Łukasz Jarosław **KOZAR** • Monika **WODNICKA**

BLOCKCHAIN IN ENERGY: LITERATURE REVIEW IN THE CONTEXT OF SUSTAINABILITY

Łukasz Jarosław **Kozar** (ORCID: 0000-0002-8426-8471) – *University of Lodz, Faculty of Economics and Socjology, Department of Labour and Social Policy*

Monika **Wodnicka** (ORCID: 0000-0002-9656-5713) – *University of Lodz, Faculty of Economics and Socjology, Department of Business Analisis and Strategy*

Correspondence address:
Revolution 1905 Street 37/39, 90-214 Lodz, Poland
e-mail: lukasz.kozar@uni.lodz.pl

ABSTRACT: This paper has two equally important research objectives. The first aim of the research is to identify key research areas addressed in scientific publications that simultaneously relate to blockchain, energy, and sustainability. In turn, the identification of green research areas in these publications is the second research aim. The indicated research aims were achieved on the basis of a bibliometric review of 205 scientific publications from 2017-2023 (Scopus database). By means of a systematic literature review, 25 different key research areas were identified. In turn, the classic literature review identified 18 green research areas (e.g. green blockchain). At the same time, no green issue was identified as a key research area. The results can inspire researchers looking for research gaps around blockchain and sustainability issues. Among the recommendations for stakeholders, the need for further research around blockchain technology, the development of a regulatory framework, or educational issues were highlighted.

KEYWORDS: blockchain, energy, green blockchain, sustainability

 DOI: 10.34659/eis.2024.90.3.866

Introduction

Nowadays, the issue of sustainability plays a very important role in the scientific discourse, where it is addressed in the context of various research questions (e.g. Kozar, 2023; Soini & Birkeland, 2014; Wodnicka, 2020). At the same time, it should be emphasised that more and more often in scientific deliberations referring to sustainability issues, specific solutions implemented in the practice of various market entities are discussed. The implementation of sustainability into the practice of socio-economic life stimulates the green transition currently taking place, as a result of which a reduction in the negative impact of society and the economy on the environment can be observed. Hence, more and more researchers are addressing the issue of the role and importance of sustainability in economic practice by addressing the issue of green transition in specific sectors of the economy (e.g. Magyari et al., 2022; Mallett & Pal, 2022; Ouyang et al., 2023). One of the sectors that is undergoing a green transition process and is at the same time counted among the key sectors without which modern socio-economic life cannot function is the energy sector (e.g. Pegels et al., 2018; Plotkin et al., 2023).

Sustainability-oriented changes in the energy sector, as shown by previous research, are the result of the implementation of various sustainable (e.g. Baloch et al., 2024) or green practices (e.g. Fyliuk & Kuznetsova, 2018; Krishankumar et al., 2024). However, regardless of the name of the practices that are used by researchers in the scientific discourse around sustainable development practices, it should be pointed out that they are gradually contributing to a decrease in the negative environmental impact of the energy sector. At the same time, taking into account the specifics of the energy sector, it has to be emphasised that technological changes are considered to be a key to reducing its negative impact on the environment. Therefore, new technologies can be seen as an opportunity to reduce the sector's carbon footprint while improving its efficiency. A technology that is seen as an opportunity for change towards a more sustainable and greener energy sector is blockchain technology, which is already being used in many areas of the energy sector (e.g. Khatoon et al., 2019; Ma et al., 2024; Miglani et al., 2020).

The research presented in this article has two equally important research aims. The first research aim is to identify key research areas addressed in scientific publications that are simultaneously related to blockchain, energy, and sustainability. The second research aim is to identify green research areas addressed in scientific publications that are simultaneously related to blockchain, energy, and sustainability. In the opinion of the authors of this article, it is important to pay attention to green research questions as they can show whether blockchain is being considered in academic deliberations in the ongoing process of green transition in the energy sector. The study used the Scopus database within the scope of which the author's research question was formulated (Q1- described in detail in the materials and methodology section). The constructed study is characterised by the possibility of its replication by the authors or other researchers in the future. Thus, it has a comparison value in the context of current and future research on oriented issues in the energy sector, where at the same time the issues of sustainable development are raised. The results of the analysis are presented in the form of generated bibliometric maps using the VOSviewer software (version 1.6.20).

In this article, six structurally and functionally closely related parts are distinguished. In the introduction, an overview of the undertaken research problem is presented. In addition, the aims of the analysis undertaken are indicated in this section. The second part presents some selected issues of scientific discourse around the blockchain issue. The third part presents the materials and describes in detail (step by step) the adopted research activities, which provides the reproducibility of the research undertaken. The next part focuses on a synthetic description of the obtained results (in particular, the visualisation of the data in tabular layout and bibliometric maps). The penultimate part contains a discussion. The author's observations on future promising research directions related to the issues of the green labour market and subversive innovation are, among others important elements of this part. The scientific discussion has come up with some conclusions regarding the implications for potential stakeholders.

DOI: 10.34659/eis.2024.90.3.866

An overview of the literature

Numerous researchers emphasise that the incorporation of blockchain technology into the energy industry can have numerous benefits (e.g. Delardas & Giannos, 2022; Schletz et al., 2020; Yontar, 2023). Specifically, it is emphasised that the technology provides full traceability of energy (Shojaei et al., 2021). Thus, it allows for the measurement of energy consumption (e.g. Di et al., 2023) or the demonstration of the source of energy (renewable or non-renewable source). In the context of sustainability issues, the blockchain makes it possible, among other things, to effectively improve the use of renewable energy and reduce overall energy consumption (Yang et al., 2023), to reduce the environmental impact of the sectors/entities concerned (e.g. Mohsin et al., 2023; Zhou, 2024), or to track the use of energy sources throughout the life cycle of a product (Shojaei et al., 2021). On the other hand, Yildizbasi (2021) refers to green energy issues in his discussion.

In some scientific publications, the blockchain is also discussed in the context of green technologies (e.g. Cocco et al., 2017; Li, 2021; Polas et al., 2022) or environmental sustainability issues (e.g. Alhasan & Hamdan, 2023; Alofi et al., 2022; Parmentola et al., 2022). Some researchers explicitly distinguish the green blockchain in their studies by referring to various energy issues (e.g. Abdulhayan, 2023; Oudani et al., 2023). Against the background of these research considerations, it can be seen that the green blockchain is seen as a kind of move towards sustainability (Alzoubi & Mishra, 2023). At the same time, the green blockchain is pointed out as an alternative to the blockchain technology and its perceived environmental impact, which has raised concerns among some researchers (Yomboi et al., 2024).

It should also be noted that the blockchain technology can reduce costs and improve efficiency in the energy sector (Jahromi et al., 2023; Yahaya et al., 2020) by optimising financial operations and physical energy systems. Thus, the technology can have an impact on improving the system reliability and increasing trust (e.g. Jayavarma et al., 2024), as well as an impact on the security of electricity generation and distribution (e.g. Das et al., 2023), including improving cyber security in the energy sector (e.g. Khubrani & Alam, 2023). A part of the researchers further recognises that the use of the blockchain in the energy sector creates a basis for peer-to-peer energy trading (e.g. Gupta et al., 2023; Tesfamicael et al., 2020; Tsao & Thanh, 2021; Wilkinson et al., 2020), which is also important for building a decentralised energy system (e.g. El Baba et al., 2020; Luo & Mahdjoubi, 2024).

Research methods

The study was carried out between October 2023 and June 2024. Four key research phases can be distinguished. Several relevant research activities were carried out at each of these stages, as shown in Figure 1. The first stage of the research was aimed at a general review of scientific publications in the field of blockchain issues (Figure 1). The Google Scholar search engine, the Scopus database, and the Web of Science database were used for this purpose, and they are commonly used by researchers in this type of preliminary analysis. The review led to the conclusion that blockchain issues are increasingly discussed in the literature, considering the issue of market segmentation (e.g. Du et al., 2022; Xu et al., 2023). The application of blockchain technology is discussed in the financial services market (e.g. Hashem, 2023; Pal et al., 2021; Treleaven et al., 2017), transportation and logistics (e.g. Ahmad et al., 2021; Tian et al., 2021; Wodnicka, 2019), the field of medicine and healthcare, IT services, and the context of energy issues (e.g. Almutairi et al., 2022; Andoni et al., 2019; Mengelkamp et al., 2018). Due to its topicality and relevance to contemporary socio-economic development, further analysis was narrowed down to the broader energy sector at this stage. At the same time, a few research gaps have been recognised in this field. There is a lack of analysis identifying key research areas addressed in scientific publications referring simultaneously to the blockchain, energy and sustainability. Also, there is a lack of analysis aimed at identifying the green research areas in such scientific publications. These issues have become targets for further research.

At the next stage, the research was conceptualised. This stage aimed to select the methods, techniques, and research tools with which to conduct the study aimed at the above-mentioned research aims. The authors decided to carry out a bibliometric analysis, which is done in the research aimed at identifying key areas of research in a certain context. For this aim, the Systematic Literature Review

DOI: 10.34659/eis.2024.90.3.866

(SLR) method was used. On the other hand, it was decided to identify the green research areas using the Classic Literature Review (CLR) method.

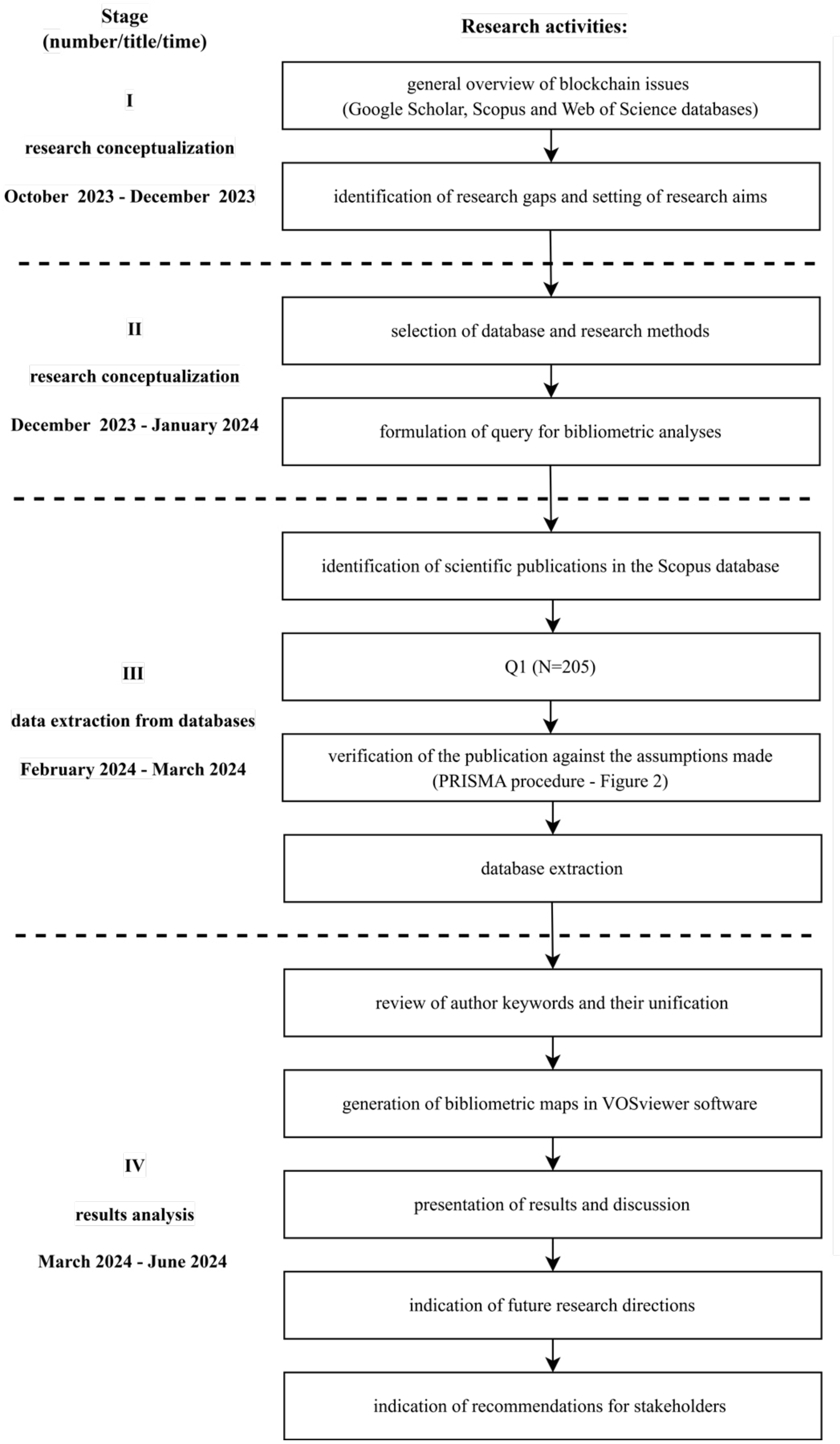

Figure 1. Research procedure stages and timeline

In both analysis, it was assumed that the author keywords used by the researchers in the scientific publications would be considered as the research areas. Furthermore, in the case of the green research areas, for the purposes of the study, it was assumed that these authors' keywords would be those that are simply referred to as green in the analysed scientific publications. This is the term generally used by the individual authors to emphasise the distinctiveness of the discussed issues in the previous non-green approaches. Thus, the term green is used to emphasise that the issue in question is associated with pro-environmental values and, at the same time, is closely linked to sustainability. At the same time, the Scopus database was chosen for the analysis, which is characterised by the relevant bibliometric recording of the quality of data noted by the researchers, strictly defined indexing standards for scientific journals, and is also used in bibliometric analysis focused on exploring the blockchain issues (e.g. Mulligan et al., 2024; Rejeb & Zailani, 2023; Wang & Su, 2020), broad energy issues (e.g. Kozar & Sulich, 2023b; Sarkodie & Owusu, 2020; Sulich & Sołoducho-Pelc, 2022) and sustainable development (e.g. Joshi et al., 2023; Kozar & Sulich, 2023a). For the planned analyses in the Scopus database, a Q1 bibliometric query was also formulated at this stage (Table 1). The choice of database for analysis, the research methods and the constructed query itself are the limiting factors of the study. Nevertheless, at the same time, the same assumptions guarantee the transparency of the individual procedures and their reproducibility. It is also assumed here that the discussion planned at the final stage of the research and the demonstration of future research directions will be additionally supported by the CLR method, within the scope of which the content of entire scientific studies will be analysed. The adoption of the research assumptions (further described below) and the construction of a query to the Scopus database allowed the research to proceed to the next stage.

Table 1. Search Query syntax details

Symbol	Query Syntax	No. Results (9 February 2024)
Q1	TITLE-ABS-KEY (((blockchain OR "block-chain") AND energy AND ("sustainable development" OR sustainability))) AND PUBYEAR > 2016 AND PUBYEAR < 2024 AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re"))	205

The third stage of the research began with a search of the titles, abstracts and keywords of the scientific publications contained in the Scopus database in terms of the variables defined in the query Q1. It should be noted that the bibliometric query excluded publications published in 2024. This aspect was intentional and results from the good practice of the bibliometric analysis, in which, in general, to ensure the transparency and comparability of their studies in the future, the researchers do not analyse publications from the year in which the analysis is conducted (high risk of variability in the number of publications meeting the query over time due to the open publication process for that year). In addition, as shown in Table 1, the search covered only publications in English (a necessary aspect for the correctness of analysis targeting keywords with both the SLR and CLR methods), which were assigned according to the source type of a journal, with a final status in the publication stage, and with document type of an article or a review. Based on the bibliometric query constructed in this way, 205 scientific publications were selected from the Scopus database. The five most cited publications are presented with an indication of the number of citations in Table 2.

As shown in Figure 2, the 205 identified scientific publications included 171 articles and 44 reviews. All these scientific publications were subjected to a checking procedure based on the PRISMA scheme to ensure that they met the requirements for the planned bibliometric analysis. First of all, it was verified whether there were any duplicates (the same publication entered more than once in the Scopus database) in the range of the analysed scientific publications. The author's keywords from possible duplicate publications could lead to a distortion of the study results. In the next step, those scientific publications without the assigned author keywords were verified and removed from the set of scientific publications (not in all scientific journals; author keywords are constructed by the authors and shown in the publication). After this analysis, it was again verified that only scientific publications with the keywords in English and the corresponding publication date were obtained through bibliometric querying (as presented above, scientific publications from 2024 were excluded

DOI: 10.34659/eis.2024.90.3.866

from the analyses). As a result of the above analysis and the exclusions that followed, 192 scientific publications were found to meet the requirements for further analysis (152 articles and 40 reviews). Therefore, the scientific publications selected in this way were extracted from the Scopus database in a format that would enable their further analysis at the next stage of the study in the VOSviewer software.

Table 2. The five most frequently cited publications on the analysed issues

Document title	Authors and data	Journal title	Cited by
Blockchain for the future of sustainable supply chain management in Industry 4.0	Esmaeilian et al. (2020)	Resources, Conservation and Recycling	369
State of the art of machine learning models in energy systems, a systematic review	Mosavi et al. (2019)	Energies	308
Blockchain-empowered sustainable manufacturing and product lifecycle management in industry 4.0: A survey	Leng et al. (2020)	Renewable and Sustainable Energy Reviews	275
Sustainability of bitcoin and blockchains	Vranken (2017)	Current Opinion in Environmental Sustainability	272
Decarbonizing Bitcoin: Law and policy choices for reducing the energy consumption of Blockchain technologies and digital currencies	Truby (2018)	Energy Research and Social Science	236

Source: authors' elaboration based on the Scopus database [09-02-2024].

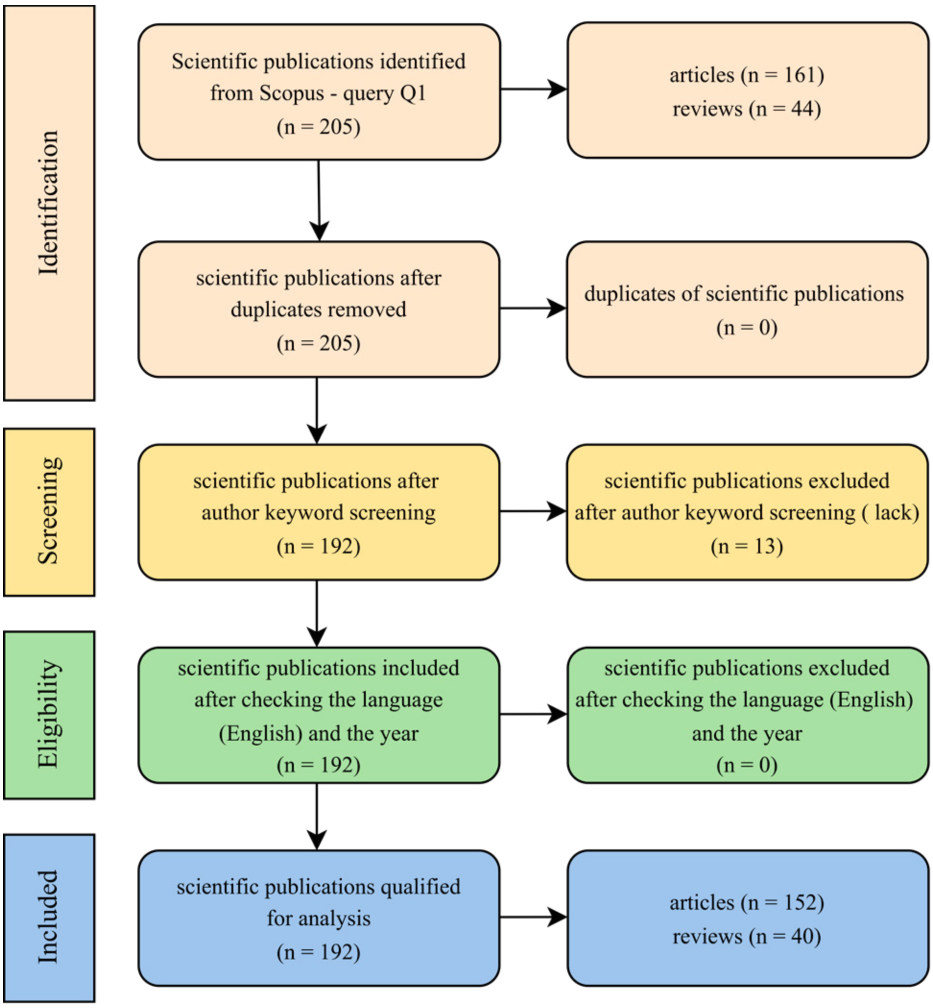

Figure 2. PRISMA procedure – verification of selected publications for study

DOI: 10.34659/eis.2024.90.3.866

Before the research results were generated in the form of bibliometric maps, all author keywords assigned to the scientific publications selected for the study were identified and reviewed. The result of this analysis was the extraction of 719 author keywords. At the same time, it was noticed that the form in which the author's keywords were written varied, which could affect the quality and size of the bibliometric maps. Therefore, the author's keywords were unified (Table 3). The procedure for replacing author keywords was intended to improve the quality of the resulting data and its visualisation. It was assumed that the following would be replaced:

- abbreviations or full names of words together with the abbreviation – the full name of the author keyword in question,
- author's words in singular and plural form, or in different versions of English (British, American) with one variant of the word (the word with the most frequent occurrence and, in the case of similar values of this index, the highest value of the index of overall link strength),
- keywords with errors (e.g. typos in the spelling of words) with the correct version of the word.

Table 3. Unification process for author keywords included in bibliometric maps

Replaced author keyword	Replacement keyword	Replaced author keyword	Replacement keyword
ai	artificial intelligence	prosumers	prosumer
bc	blockchain	renewable energy (re)	renewable energy
blochcian	blockchain	sdgs	sustainable development goals
block chain	blockchain	smart cities	smart city
circular economy (ce)	circular economy	smart contract	smart contracts
internet of things (iot)	internet of things	smart grid (sg)	smart grid
iot	internet of things	smartgrid	smart grid
iots	internet of things	supply chains	supply chain
ml	machine learning	sustainable development	sustainability
proof-of-work	proof of work	sustainable development goal	sustainable development goals

Source: authors' elaboration based on the Scopus database [09-02-2024].

The substitution procedure was carried out in 54 cases, which ultimately contributed to qualifying 668 author keywords for further analysis, based on which it was possible to create the bibliometric maps in the VOSviewer software.

Results of the research

The minimum number of co-occurrences of authored keywords adopted for the analysis aimed at presenting the results in the form of bibliometric maps was five. Of the selected unique author keywords participating in the analysis, 25 met the research threshold. On the basis of the author keywords thus selected, a visualisation of their linkage network was generated using the VOSviewer software (Figure 3). A bibliometric map of links consisting of five clusters was created. This bibliometric map shows the most frequently used author keywords in scientific publications where the blockchain, energy and sustainability were referenced in the title, abstracts and/or keywords. Furthermore, it should be noted that each author keyword is assigned to one cluster only.

The author keywords in Figure 3 are labelled as nodes (dots in different colours denoting cluster membership) with captions. They vary in size. The author keyword characterised by the highest number of occurrences in the analysed scientific publications takes on the largest size. For author keywords having the same value of co-occurrences, the sizes of the nodes are identical. Between the nodes, there are lines representing the connections between the individual author keywords. They indicate with which author keywords a given word co-occurs in the analysed scientific publications.

DOI: 10.34659/eis.2024.90.3.866

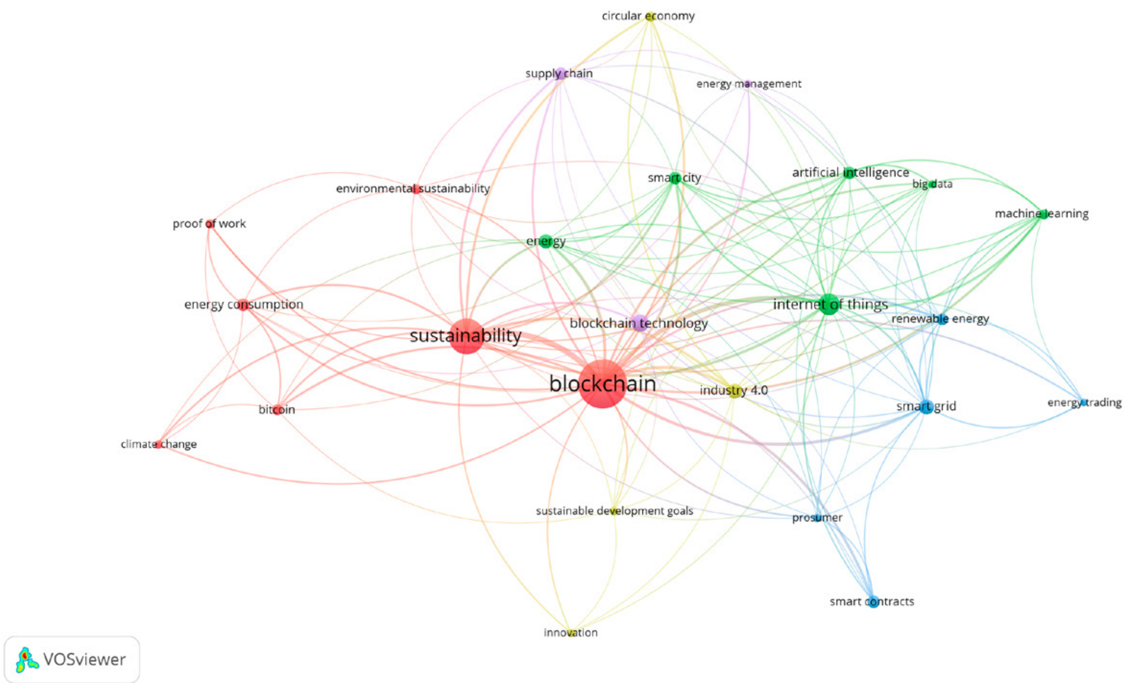

Figure 3. Author keywords co-occurrences in full counting method of Q1 results

Source: authors' elaboration in VOSviewer software (1.6.20 version).

The structure of each of the five clusters is further presented in Table 4, where the order of the listed author keywords follows only from their alphabetical order. The author's keywords that appear most frequently in the analysed scientific publications are the blockchain (red cluster), the sustainability (red cluster), the internet of things (green cluster), the blockchain technology (purple cluster), the smart grid (blue cluster) and the industry 4.0 (yellow cluster). The indicated issues should be considered as the most important research threads addressed by the researchers in the analysed scientific publications, which referred to the blockchain, the broadly defined issue of energy (the word in the bibliometric query energy) and sustainability.

Table 4. Clusters of author's keywords co-occurrences visible in Figure 3

Cluster	Color	Keywords
1	Red	bitcoin (O = 9, L = 8, TLS = 21); blockchain (O = 122, L = 23, TLS = 204); climate change (O = 6, L = 5, TLS = 12); energy consumption (O = 12, L = 9, TLS = 24); environmental sustainability (O = 8, L = 9, TLS = 11); proof of work (O = 7, L = 5, TLS = 12); sustainability (O = 70, L = 23, TLS = 133);
2	Green	artificial intelligence (O = 12, L = 14, TLS = 38); big data (O = 6, L = 10, TLS = 24); energy (O = 14, L = 15, TLS = 37); internet of things (O = 29, L = 19, TLS = 79); machine learning (O = 8, L = 10, TLS = 34); smart city (O = 11, L = 14, TLS = 39)
3	Blue	energy trading (O = 5, L = 6, TLS = 12); prosumer (O = 6, L = 9, TLS = 13); renewable energy (O = 10, L = 12, TLS = 24); smart contracts (O = 11, L = 7, TLS = 20); smart grid (O = 16, L = 17, TLS = 43)
4	Yellow	circular economy (O = 8, L = 7, TLS = 20); industry 4.0 (O = 16, L = 13, TLS = 38); innovation (O = 6, L = 5, TLS = 9); sustainable development goals (O = 6, L = 9, TLS = 11);
5	Purple	blockchain technology (O = 21, L = 12, TLS = 19); energy management (O = 5, L = 8, TLS = 10); supply chain (O = 11, L = 11, TLS = 25)

O – number of co-occurrences, L – number of links, TLS – total link strength.

An overlay bibliometric map was also generated using the VOSviewer software (Figure 4). This map shows the change over time of the research topic in the analysed scientific publications. It is characterised by the fact that the brighter the colour, the more topical the research area. Thus, one can see that the following issues are the most topical areas of research combining blockchain, energy and sustainable development: artificial intelligence, climate change, and sustainable development goals.

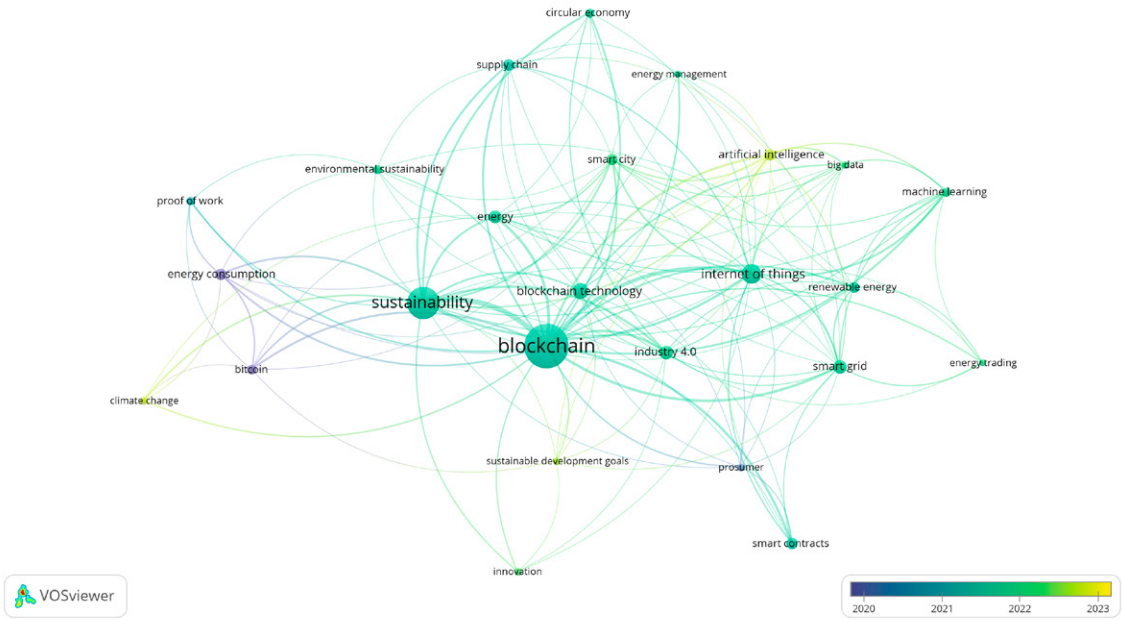

Figure 4. Overlay map of the author's keywords co-occurrences

Source: authors' elaboration in VOSviewer software (1.6.20 version).

Additionally, bibliometric maps were generated for two author keywords referring to the blockchain issues (Figure 5 and Figure 6). The blockchain technology is linked to 12 author keywords belonging to the red (energy consumption, environmental sustainability, sustainability), the green (energy, internet of things), the blue (prosumer, smart contracts, smart grid), the yellow (industry 4.0, sustainable development goals) and the purple (energy management, supply chain) clusters.

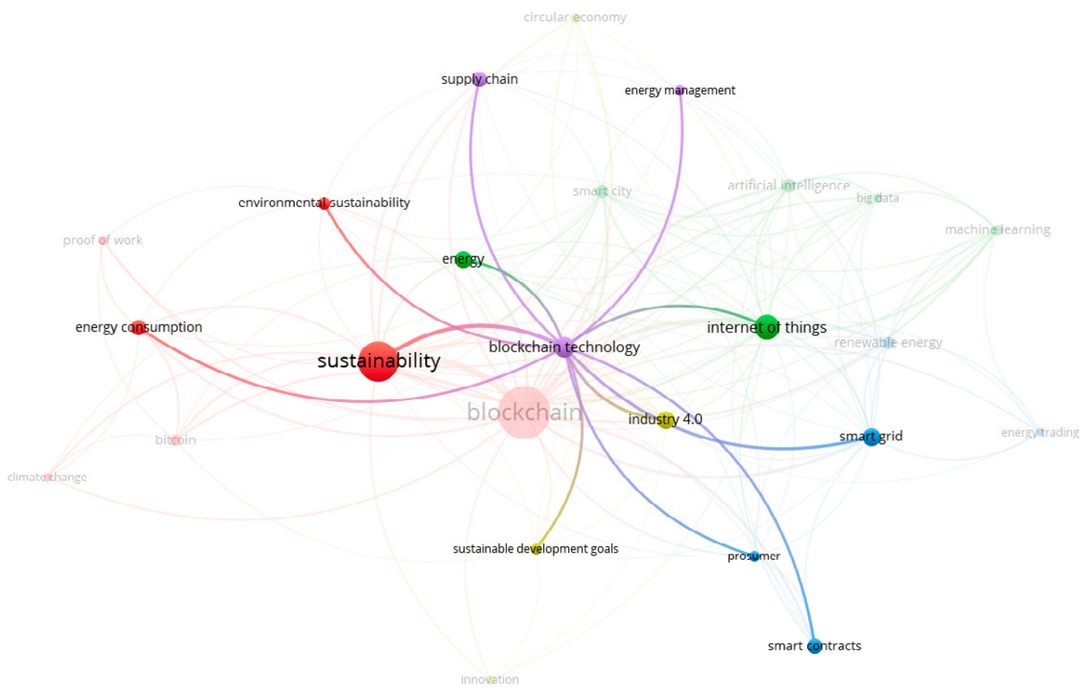

Figure 5. Keyword blockchain technology relations with other keywords

Source: authors' elaboration in VOSviewer software (1.6.20 version).

DOI: 10.34659/eis.2024.90.3.866

In Figure 6, a bibliometric linkage map for the author's blockchain keyword is visualised. The word is not exclusively linked to the blockchain technology. The aspect indicated is the result of the fact that the blockchain is considered a technology. Hence, there is no reason to display the same meaningful terms side by side in the keywords.

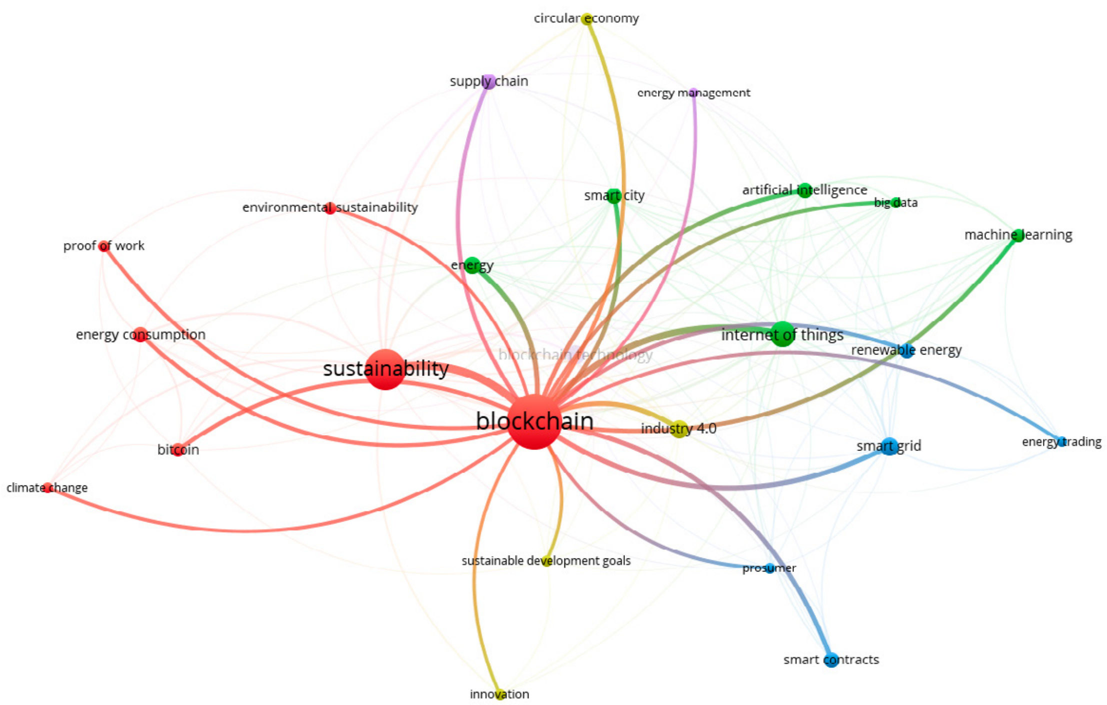

Figure 6. Keyword blockchain relations with other keywords

Source: authors' elaboration in VOSviewer software (1.6.20 version).

The results of the analysis presented above in Figures 3-6 and Table 4 will be discussed later in the article. Based on this argument, promising research directions will be determined in the future. The bibliometric maps presented do not contain any reference to the green research areas. Nevertheless, the analysis of the scientific publications selected for the bibliometric research conducted with the CLR method shows that this topic is gradually appearing in the circle of research interests of individual authors. Then, as the authors of this article note, researchers add the word 'green' to denote the issue in question. In the scientific publications reviewed in relation to this practice, references to green IT (Guillaume et al., 2022; Powell et al., 2021; Veit & Thatcher, 2023), the green blockchain (Alzoubi & Mishra, 2023; Varavallo et al., 2022), the green bonds (Naderi & Tian, 2022; Pombo-Romero & Rúas-Barrosa, 2022), the green computing (Guillaume et al., 2022; Oudani et al., 2023), the green finance (Dorfleitner et al., 2021; Naderi & Tian, 2022) and the green technology (Heinonen et al., 2022; Riyal et al., 2022). In addition, references to the green economy (Polas et al., 2022), the green entrepreneurship (Polas et al., 2022), green HR (Sharma et al., 2022), the green infrastructure (Giudicianni et al., 2020), the green innovation (Polas et al., 2022), the green IS (Veit & Thatcher, 2023), the green logistics (Pham et al., 2023), the green manufacturing (Prasad et al., 2022), the green procurement (Rane & Thakker, 2019), the green product design (Rane et al., 2023), the green supply chain management (Labaran & Masood, 2023), or the green technology innovation issues (Li, 2021). In the opinion of the authors of this article, the growing interest in the green issues due to their close connection with sustainability and the ongoing green transition of the energy sector will be reflected in the emergence of green research areas in the key research areas.

DOI: 10.34659/eis.2024.90.3.866

Discussion

The articles taken for analysis in the bibliometric study carried out referred in their content to the issue of the blockchain in various aspects. Some of these articles were reviewed. Most often, these studies used the Scopus (e.g. Espina-Romero et al., 2022; Yang et al., 2023) or Web of Science (e.g. Wu et al., 2022; Zha et al., 2022) databases or both simultaneously (e.g. Ayan et al., 2022; Biegańska, 2022; Rejeb & Zailani, 2023) as the data source for the planned analysis. Nevertheless, it is important to recognise that the studies conducted to date have addressed the blockchain in energy issues to varying degrees. In some studies, the use of the words the blockchain and the energy has occurred in the constructed bibliometric query, albeit with no reference to sustainability in these queries (e.g. Wang & Su, 2020). On the other hand, a much broader research focus can be discerned. Some of these also do not refer to sustainability issues, but in addition to the issues of blockchain and energy, there are references to, e.g. the smart grid (e.g. Biegańska, 2022), and buildings (e.g. Yang et al., 2023). In contrast, Wu et al. (2022) refer to the issue of the blockchain in energy through the lens of sustainability in their research but do not focus exclusively on the blockchain issue (the bibliometric query references the Internet of things and artificial intelligence, among others). The studies where there was no reference to the energy and/or the blockchain issues in the bibliometric query, but these issues were identified as important directions for future research (e.g. Ayan et al., 2022; Espina-Romero et al., 2022), economic challenges (e.g. Lai et al., 2023), or were the result of analyses and/or discussions undertaken (e.g. Labaran & Masood, 2023; Rejeb & Zailani, 2023; Shishehgarkhaneh et al., 2023; Suta & Tóth, 2023) are worth pointing out. The study presented in this article differs from the above-mentioned ones in the syntax of the bibliometric query (the words explored are block-chain, blockchain, energy, sustainable development, and sustainability). The study thus brings new cognitive value regarding the key research areas undertaken in the context of blockchain in energy in the context of sustainable development.

Sustainable energy transition can be supported through blockchain technology (Gupta et al., 2023). Combining this technology with the smart grid, as highlighted by the researchers, can result in increased energy system capacity (Çelik et al., 2022). Blockchain can be used to improve energy efficiency (e.g. Hossin et al., 2023; Varriale et al., 2020). Thus, the technology can support the achievement of the environmental sustainability goals (e.g. Böhmecke-Schwafert & García Moreno, 2023; Calandra et al., 2023; Parmentola et al., 2022). At the same time, the blockchain field has seen a call for the technology to pursue more sustainable and energy-efficient solutions (Nurgazina et al., 2021). It is recognised that without the implementation of appropriate technological modifications, the blockchain networks may even endanger the ambitious sustainability-oriented plans due to their increasing carbon footprint (Truby et al., 2022). In the opinion of the authors of this article, such a noticeable dichotomy in the scientific considerations of the issue at hand is very important, as it allows us to see both the opportunities and the threats from the blockchain for sustainability-oriented activities. Nevertheless, it should be noted that with the development of blockchain technology, it should be expected that its energy efficiency will increase, which in turn will translate into an increase in the number of scientific studies indicating the application of this technology in the green transition of the economy.

The study also identified the green research areas. Within the scope of the identified green research areas, however, no references to the green labour market issues, and in particular the green jobs that are part of it, were observed. This observation has a very important scientific implication. Indeed, it should be emphasised here that the issues related to the green labour market are now an increasingly important field of consideration for the researchers addressing issues of sustainable development (e.g. Kozar & Sulich, 2023a; Stanef-Puică et al., 2022) or the green transition of the energy sector (e.g. Kozar & Sulich, 2023b). Hence, in the opinion of the authors of this article, future studies targeting the impact of blockchain technology on the emergence of green jobs in the energy sector undergoing a green transition should be expected. The area of research thus identified definitely has a research gap discernible through the prism of the analyses carried out.

Also, a promising direction of scientific consideration in the field of blockchain and energy in the context of sustainability issues is the issue of disruptive innovations, which are sometimes also referred to as subversive innovations by researchers (e.g. Dong, 2018; Zhang et al., 2022; Zhao, 2022). This area, like the green issue, also does not appear explicitly expressed by the author’s keyword in

DOI: 10.34659/eis.2024.90.3.866

the bibliometric maps obtained. Nevertheless, this issue is beginning to be addressed in the context of blockchain problematics, which may provide a clue for future researchers. In the opinion of the authors of this article, the indicated aspect should be discussed through the prism of the ongoing transition in the energy sector (especially from the perspective of the dynamics taking place and the direction of transition in the energy sector, as well as the impact on the carbon footprint).

Conclusions

The main conclusion of this article is that the issue of blockchain is being discussed from a sustainability perspective in different research approaches. As shown, new research in this area focuses on artificial intelligence, climate change and sustainable development goals. The scientific contribution of this article is to present existing research on the blockchain in energy through the lens of sustainable development. The green research areas were also identified. Therefore, the survey that was constructed and conducted filled two research gaps.

The methodology used was the main limiting factor of the study. This was particularly true for the choice of database to be analysed (Scopus database) and the bibliometric query constructed. Hence, by applying the indicated query to other databases (e.g. Web of Science), the results of the study may differ, which is simply due to the indexing procedure in the individual scientific journal databases. Nevertheless, it is impossible to select a database that would include all scientific publications that simultaneously referred to the blockchain, energy and sustainability issues (some publications are not included in any database). The indicated research snapshot thus represents the author's research framing around the identification of the major and the green research areas in the scientific publications that simultaneously referred to the blockchain, energy and sustainability issues. Furthermore, thanks to the detailed planned and presented methodology, the study is replicable. Thus, it can be compared with other studies on blockchain issues.

Based on the analyses carried out, it is possible to identify the recommendations targeted at some specific stakeholder groups that are linked to the issue of blockchain and sustainability. First and foremost, we recognise that in order for the blockchain to support the transformation of the economy towards sustainable development to a greater extent than at present, it is necessary to develop new solutions to improve the energy efficiency of this technology. Hence, we see the need to build and support the partnerships between academia, industry and public institutions aimed at developing solutions to stimulate action aimed at sustainable blockchain technological innovation in the energy sector. It is becoming necessary, for example, to develop and systematically update legal regulations that would make it possible to reduce the costs of research using this technology (introducing various types of tax relief for research and development activities). Such solutions could encourage the business sector to finance or co-finance research projects related to blockchain technology and its application in the energy sector. It is also apparent that there is a need to create funds for interdisciplinary research aimed at practical applications of blockchain technology in the energy sector undergoing a green transition, which the research institutions and the academic centres could request.

With the rise of blockchain technology, energy sector players should include in their strategic plans the possibility of developing this technology that takes sustainability-oriented challenges into account. This includes the development of the green blockchain technology. Hence, the individual actors should not become attached to particular blockchain technology but constantly monitor new developments in order to simultaneously be more competitive in the market through the use of more energy-efficient blockchain technologies. These entities should also use the blockchain pilot implementations to test how they perform under the given conditions (verifying whether the implementation of the blockchain into the realities of an economic entity's operation will contribute to reducing its negative environmental impact) before applying it on a wider scale.

The legislators should, in our opinion, also lean towards developing a regulatory framework that facilitates the implementation of blockchain-based solutions in the energy distribution and the production process, which at the same time would support the achievement of sustainability goals for the economy. It also becomes imperative to raise awareness among the various stakeholders on the benefits and challenges of integrating the blockchain into the energy management system. It is also worthwhile for universities to introduce degree programmes on blockchain technology into their

DOI: 10.34659/eis.2024.90.3.866

educational of ferings, which would enable the energy sector stakeholders to acquire employees trained in this field. Of course, in such a focused educational offer, the emphasis beyond blockchain technology should also be on sustainability issues.

In summarising the argument, the multidimensionality of the addressed research issues concerning blockchain in energy through the prism of sustainable development should be recognised. At the same time, it is important to note the new emerging challenges related to technological development and the green transition of the economy, which are already projected and will continue to shape the directions of research undertaken in the field of blockchain in the energy sector in the coming years. Hence, future researchers should be expected to be able to combine at least the 'green' issues with the blockchain and the accompanying sustainability issues. This, of course, also makes it necessary for the researchers to develop their competencies in this area.

The contribution of the authors

Conceptualization, Ł.J.K. and M.W.; literature review, Ł.J.K. and M.W.; methodology, Ł.J.K. and M.W.; formal analysis, Ł.J.K. and M.W.; writing, Ł.J.K. and M.W.; conclusions and discussion, Ł.J.K. and M.W.

The authors have read and agreed to the published version of the manuscript.

References

Abdulhayan, S. (2023). Green blockchain technology for sustainable smart cities. In S. Krishnan, R. Kumar & V.E. Balas (Eds.), *Green Blockchain Technology for Sustainable Smart Cities* (pp. 237-262). Elsevier. https://doi.org/10.1016/B978-0-323-95407-5.00014-1

Ahmad, R. W., Hasan, H., Jayaraman, R., Salah, K., & Omar, M. (2021). Blockchain applications and architectures for port operations and logistics management. Research in Transportation Business & Management, 41, 100620. https://doi.org/10.1016/j.rtbm.2021.100620

Alhasan, H., & Hamdan, A. (2023). Blockchain Technology and Environmental Sustainability. In R. El Khoury & N. Nasrallah (Eds.), *Emerging Trends and Innovation in Business and Finance. Contributions to Management Science* (pp. 735-745). Singapore: Springer. https://doi.org/10.1007/978-981-99-6101-6_54

Almutairi, K., Hosseini Dehshiri, S. J., Hosseini Dehshiri, S. S., Hoa, A. X., Arockia Dhanraj, J., Mostafaeipour, A., Issakhov, A., & Techato, K. (2022). Blockchain Technology Application Challenges in Renewable Energy Supply Chain Management. Environmental Science and Pollution Research, 30(28), 72041-72058. https://doi.org/10.1007/s11356-021-18311-7

Alofi, A., Bokhari, M. A., Bahsoon, R., & Hendley, R. (2022). Optimizing the Energy Consumption of Blockchain-Based Systems Using Evolutionary Algorithms: A New Problem Formulation. IEEE Transactions on Sustainable Computing, 7(4), 910-922. https://doi.org/10.1109/TSUSC.2022.3160491

Alzoubi, Y. I., & Mishra, A. (2023). Green blockchain – A move towards sustainability. Journal of Cleaner Production, 430, 139541. https://doi.org/10.1016/j.jclepro.2023.139541

Andoni, M., Robu, V., Flynn, D., Abram, S., Geach, D., Jenkins, D., McCallum, P., & Peacock, A. (2019). Blockchain technology in the energy sector: A systematic review of challenges and opportunities. Renewable and Sustainable Energy Reviews, 100, 143-174. https://doi.org/10.1016/j.rser.2018.10.014

Ayan, B., Güner, E., & Son-Turan, S. (2022). Blockchain Technology and Sustainability in Supply Chains and a Closer Look at Different Industries: A Mixed Method Approach. Logistics, 6(4), 85. https://doi.org/10.3390/logistics6040085

Baloch, M. A., Qiu, Y., & Guo, Z. (2024). Empowering sustainability practices through energy transition: The role of digital economy and technological innovation among BRICS economies. Australian Economic Papers, 63(2), 283-301. https://doi.org/10.1111/1467-8454.12330

Biegańska, M. (2022). IoT-Based Decentralized Energy Systems. Energies, 15(21), 7830. https://doi.org/10.3390/en15217830

Böhmecke-Schwafert, M., & García Moreno, E. (2023). Exploring blockchain-based innovations for economic and sustainable development in the global south: A mixed-method approach based on web mining and topic modeling. Technological Forecasting and Social Change, 191, 122446. https://doi.org/10.1016/j.techfore.2023.122446

Brock, J. K.-U., & Kohli, A. K. (2023). The emerging world of digital exploration services. Journal of Business Research, 155, 113434. https://doi.org/10.1016/j.jbusres.2022.113434

Calandra, D., Secinaro, S., Massaro, M., Dal Mas, F., & Bagnoli, C. (2023). The link between sustainable business models and Blockchain: A multiple case study approach. Business Strategy and the Environment, 32(4), 1403-1417. https://doi.org/10.1002/bse.3195

Çelik, D., Meral, M. E., & Waseem, M. (2022). Investigation and analysis of effective approaches, opportunities, bottlenecks and future potential capabilities for digitalization of energy systems and sustainable development goals. Electric Power Systems Research, 211, 108251. https://doi.org/10.1016/j.epsr.2022.108251

Cocco, L., Pinna, A., & Marchesi, M. (2017). Banking on Blockchain: Costs Savings Thanks to the Blockchain Technology. Future Internet, 9(3), 25. https://doi.org/10.3390/fi9030025

Das, S., Swapnarekha, H., & Vimal, S. (2023). Integration of Blockchain Technology with Renewable Energy for Sustainable Development: Issues, Challenges and Future Direction. *Proceedings of CIPR 2023,* Howrah, India, 725, 595-607. https://doi.org/10.1007/978-981-99-3734-9_48

Delardas, O., & Giannos, P. (2022). Towards Energy Transition: Use of Blockchain in Renewable Certificates to Support Sustainability Commitments. Sustainability, 15(1), 258. https://doi.org/10.3390/su15010258

Di, L., Wang, X., Zhang, X., Ning, Y., Zhu, Y., & Wang, Y. (2023). Research of Blockchain Technology on the Application of Data Sharing Mechanism to the Energy Measurement of Power Demand Side. *Proceedings of IEEE International Conference on Image Processing and Computer Applications (ICIPCA),* Changchun, China, 1119-1123. https://doi.org/10.1109/ICIPCA59209.2023.10257896

Dong, X. (2018). A method of image privacy protection based on blockchain technology. *Proceedings of International Conference on Cloud Computing, Big Data and Blockchain (ICCBB),* Fuzhou, China, 1-4. https://doi.org/10.1109/ICCBB.2018.8756447

Dorfleitner, G., Muck, F., & Scheckenbach, I. (2021). Blockchain applications for climate protection: A global empirical investigation. Renewable and Sustainable Energy Reviews, 149, 111378. https://doi.org/10.1016/j.rser.2021.111378

Du, W., Ma, X., Yuan, H., & Zhu, Y. (2022). Blockchain technology-based sustainable management research: the status quo and a general framework for future application. Environmental Science and Pollution Research, 29(39), 58648-58663. https://doi.org/10.1007/s11356-022-21761-2

El Baba, H., Derhem, A., Al-Hindwan, H., & Pangracious, V. (2020). A Decentralized Autonomous Ecosystem for Peer-To-Peer Clean Energy Trade. *Proceedings of 12th Annual Undergraduate Research Conference on Applied Computing (URC),* Dubai, United Arab Emirates, 1-5. https://doi.org/10.1109/URC49805.2020.9099186

Esmaeilian, B., Sarkis, J., Lewis, K., & Behdad, S. (2020). Blockchain for the future of sustainable supply chain management in Industry 4.0. Resources, Conservation and Recycling, 163, 105064. https://doi.org/10.1016/j.resconrec.2020.105064

Espina-Romero, L., Guerrero-Alcedo, J., Noroño Sánchez, J. G., & Ochoa-Díaz, A. (2022). What Are the Topics That Business Ecosystems Navigate? Updating of Scientific Activity and Future Research Agenda. Sustainability, 14(23), 16224. https://doi.org/10.3390/su142316224

Fyliuk, H., & Kuznetsova, M. (2018). Technological modernization of energy companies as basis for their sustainable development. International Journal of Energy Economics and Policy, 8(3), 160-167. https://www.econjournals.com/index.php/ijeep/article/view/6294

Giudicianni, C., Herrera, M., di Nardo, A., Adeyeye, K., & Ramos, H. M. (2020). Overview of Energy Management and Leakage Control Systems for Smart Water Grids and Digital Water. Modelling, 1(2), 134-155. https://doi.org/10.3390/modelling1020009

Guillaume, B., Benjamin, D., & Vincent, C. (2022). Review of the Impact of IT on the Environment and Solution with a Detailed Assessment of the Associated Gray Literature. Sustainability, 14(4), 2457. https://doi.org/10.3390/su14042457

Gupta, J., Jain, S., Chakraborty, S., Panchenko, V., Smirnov, A., & Yudaev, I. (2023). Advancing Sustainable Energy Transition: Blockchain and Peer-to-Peer Energy Trading in India's Green Revolution. Sustainability, 15(18), 13633. https://doi.org/10.3390/su151813633

Hashem, A. (2023). The Impact of Blockchain Technology on Financial Services: Mediating Role of Big Data Analytics. Journal of Logistics, Informatics and Service Science, 10(2), 91-107. https://doi.org/10.33168/JLISS.2023.0207

Heinonen, H. T., Semenov, A., Veijalainen, J., & Hämäläinen, T. (2022). A Survey on Technologies Which Make Bitcoin Greener or More Justified. IEEE Access, 10, 74792-74814. https://doi.org/10.1109/ACCESS.2022.3190891

Hossin, M. A., Akorsu, P. K., & Abudu, H. (2023). Regional energy and carbon emissions concerns: Towards cleaner energy transition in Middle East and North Africa. Social Sciences & Humanities Open, 8(1), 100705. https://doi.org/10.1016/j.ssaho.2023.100705

Jahromi, M. J. H., Hosseini Bamakan, S. M., Qu, Q., & Tabbakhian, H. (2023). The capability of Distributed Generation in Digital Twin platform. Procedia Computer Science, 221, 1208-1215. https://doi.org/10.1016/j.procs.2023.08.108

Jayavarma, A., Preetha, P. K., & Nair, M. G. (2024). A secure energy trading in a smart community by integrating Blockchain and machine learning approach. Smart Science, 12(1), 105-120. https://doi.org/10.1080/23080477.2023.2270820

Joshi, P., Tewari, V., Kumar, S., & Singh, A. (2023). Blockchain technology for sustainable development: a systematic literature review. Journal of Global Operations and Strategic Sourcing, 16(3), 683-717. https://doi.org/10.1108/JGOSS-06-2022-0054

Khatoon, A., Verma, P., Southernwood, J., Massey, B., & Corcoran, P. (2019). Blockchain in Energy Efficiency: Potential Applications and Benefits. Energies, 12(17), 3317. https://doi.org/10.3390/en12173317

Khubrani, M. M., & Alam, S. (2023). Blockchain-Based Microgrid for Safe and Reliable Power Generation and Distribution: A Case Study of Saudi Arabia. Energies, 16(16), 5963. https://doi.org/10.3390/en16165963

Kozar, Ł. J. (2023). Self-employment and Sustainable Development-Using the ICT Solutions for Greening Economic Activity. Procedia Computer Science, 225, 468-475. https://doi.org/10.1016/j.procs.2023.10.031

Kozar, Ł. J., & Sulich, A. (2023a). Green Jobs in the Energy Sector. Energies, 16(7), 3171. https://doi.org/10.3390/en16073171

Kozar, Ł. J., & Sulich, A. (2023b). Energy Sector's Green Transformation towards Sustainable Development: A Review and Future Directions. Sustainability, 15(15), 11628. https://doi.org/10.3390/su151511628

Krishankumar, R., Ramanujam, N., Zavadskas, E. K., Ravichandran, K. S., & Gandomi, A. H. (2024). Ranking Barriers Impeding Sustainability Adoption in Clean Energy Supply Chains: A Hybrid Framework With Fermatean Fuzzy Data. IEEE Transactions on Engineering Management, 71, 5506-5522. https://doi.org/10.1109/TEM.2024.3350249

Labaran, M. J., & Masood, T. (2023). Industry 4.0 Driven Green Supply Chain Management in Renewable Energy Sector: A Critical Systematic Literature Review. Energies, 16(19), 6977. https://doi.org/10.3390/en16196977

Lai, K. E., Abdul Rahiman, N., Othman, N., Ali, K. N., Lim, Y. W., Moayedi, F., & Mat Dzahir, M. A. (2023). Quantification process of carbon emissions in the construction industry. Energy and Buildings, 289, 113025. https://doi.org/10.1016/j.enbuild.2023.113025

Leng, J., Ruan, G., Jiang, P., Xu, K., Liu, Q., Zhou, X., & Liu, C. (2020). Blockchain-empowered sustainable manufacturing and product lifecycle management in industry 4.0: A survey. Renewable and Sustainable Energy Reviews, 132, 110112. https://doi.org/10.1016/j.rser.2020.110112

Li, D. (2021). Green technology innovation path based on blockchain algorithm. Sustainable Computing: Informatics and Systems, 31, 100587. https://doi.org/10.1016/j.suscom.2021.100587

Luo, X., & Mahdjoubi, L. (2024). Towards a blockchain and machine learning-based framework for decentralised energy management. Energy and Buildings, 303, 113757. https://doi.org/10.1016/j.enbuild.2023.113757

Ma, C.-Q., Lei, Y.-T., Ren, Y.-S., Chen, X.-Q., Wang, Y.-R., & Narayan, S. (2024). Systematic analysis of the blockchain in the energy sector: Trends, issues, and future directions. Telecommunications Policy, 48(2), 102677. https://doi.org/10.1016/j.telpol.2023.102677

Magyari, J., Zavarkó, M., & Csedő, Z. (2022). Smart knowledge management driving green transformation: A comparative case study. Smart Energy, 7, 100085. https://doi.org/10.1016/j.segy.2022.100085

Mallett, A., & Pal, P. (2022). Green transformation in the iron and steel industry in India: Rethinking patterns of innovation. Energy Strategy Reviews, 44, 100968. https://doi.org/10.1016/j.esr.2022.100968

Mengelkamp, E., Gärttner, J., Rock, K., Kessler, S., Orsini, L., & Weinhardt, C. (2018). Designing microgrid energy markets. Applied Energy, 210, 870-880. https://doi.org/10.1016/j.apenergy.2017.06.054

Miglani, A., Kumar, N., Chamola, V., & Zeadally, S. (2020). Blockchain for Internet of Energy management: Review, solutions, and challenges. Computer Communications, 151, 395-418. https://doi.org/10.1016/j.comcom.2020.01.014

Mohsin, M., Naseem, S., Zia-ur-Rehman, M., Baig, S. A., & Salamat, S. (2023). The crypto-trade volume, GDP, energy use, and environmental degradation sustainability: An analysis of the top 20 crypto-trader countries. International Journal of Finance & Economics, 28(1), 651-667. https://doi.org/10.1002/ijfe.2442

Mosavi, A., Salimi, M., Ardabili, S. F., Rabczuk, T., Shamshirband, S., & Varkonyi-Koczy, A. R. (2019). State of the art of machine learning models in energy systems, a systematic review. Energies, 12(7), 1301. https://doi.org/10.3390/en12071301

Mulligan, C., Morsfield, S., & Cheikosman, E. (2024). Blockchain for sustainability: A systematic literature review for policy impact. Telecommunications Policy, 48(2), 102676. https://doi.org/10.1016/j.telpol.2023.102676

Naderi, N., & Tian, Y. (2022). Leveraging Blockchain Technology and Tokenizing Green Assets to Fill the Green Finance Gap. Energy Research Letters, 3(3). https://doi.org/10.46557/001c.33907

Nurgazina, J., Pakdeetrakulwong, U., Moser, T., & Reiner, G. (2021). Distributed Ledger Technology Applications in Food Supply Chains: A Review of Challenges and Future Research Directions. Sustainability, 13(8), 4206. https://doi.org/10.3390/su13084206

Oudani, M., Sebbar, A., Zkik, K., El Harraki, I., & Belhadi, A. (2023). Green Blockchain based IoT for secured supply chain of hazardous materials. Computers & Industrial Engineering, 175, 108814. https://doi.org/10.1016/j.cie.2022.108814

Ouyang, H., Guan, C., & Yu, B. (2023). Green finance, natural resources, and economic growth: Theory analysis and empirical research. Resources Policy, 83, 103604. https://doi.org/10.1016/j.resourpol.2023.103604

Pal, A., Tiwari, C. K., & Behl, A. (2021). Blockchain technology in financial services: a comprehensive review of the literature. Journal of Global Operations and Strategic Sourcing, 14(1), 61-80. https://doi.org/10.1108/JGOSS-07-2020-0039

Parmentola, A., Petrillo, A., Tutore, I., & De Felice, F. (2022). Is blockchain able to enhance environmental sustainability? A systematic review and research agenda from the perspective of Sustainable Development Goals (SDGs). Business Strategy and the Environment, 31(1), 194-217. https://doi.org/10.1002/bse.2882

Pegels, A., Vidican-Auktor, G., Lütkenhorst, W., & Altenburg, T. (2018). Politics of Green Energy Policy. The Journal of Environment & Development, 27(1), 26-45. https://doi.org/10.1177/1070496517747660

Pham, N. D. K., Dinh, G. H., Pham, H. T., Kozak, J., & Nguyen, H. P. (2023). Role of Green Logistics in the Construction of Sustainable Supply Chains. Polish Maritime Research, 30(3), 191-211. https://doi.org/10.2478/pomr-2023-0052

Plotkin, J., Levchenko, N., Shyshkanova, G., & Levchenko, S. (2023). Development of Energy Enterprises in the Context of Green Transformation. Journal of Engineering Sciences, 10(1), G22-G33. https://doi.org/10.21272/jes.2023.10(1).g3

Polas, M. R. H., Kabir, A. I., Sohel-Uz-Zaman, A. S. M., Karim, R., & Tabash, M. I. (2022). Blockchain Technology as a Game Changer for Green Innovation: Green Entrepreneurship as a Roadmap to Green Economic Sustainability in Peru. Journal of Open Innovation: Technology, Market, and Complexity, 8(2), 62. https://doi.org/10.3390/joitmc8020062

Pombo-Romero, J., & Rúas-Barrosa, O. (2022). A Blockchain-Based Financial Instrument for the Decarbonization of Irrigated Agriculture. Sustainability, 14(14), 8848. https://doi.org/10.3390/su14148848

Powell, L. M., Hendon, M., Mangle, A., & Wimmer, H. (2021). Awareness of blockchain usage, structure, & generation of platform's energy consumption: Working towards a greener blockchain. Issues in Information Systems, 22(1), 114-123. https://doi.org/10.48009/1_iis_2021_114-123

Prasad, S., Rao, A. N., & Lanka, K. (2022). Analysing the Barriers for Implementation of Lean-led Sustainable Manufacturing and Potential of Blockchain Technology to Overcome these Barriers: A Conceptual Framework. International Journal of Mathematical, Engineering and Management Sciences, 7(6), 791-819. https://doi.org/10.33889/IJMEMS.2022.7.6.051

Rane, S. B., & Thakker, S. V. (2019). Green procurement process model based on blockchain–IoT integrated architecture for a sustainable business. Management of Environmental Quality: An International Journal, 31(3), 741-763. https://doi.org/10.1108/MEQ-06-2019-0136

Rane, S. B., Potdar, P. R., & Aware, S. (2023). Strategies for development of smart and green products using Blockchain-IoT integrated architecture. Operations Management Research, 16(4), 1830-1857. https://doi.org/10.1007/s12063-023-00398-5

Rejeb, A., & Zailani, S. (2023). Blockchain Technology and the Circular Economy: A Systematic Literature Review. Journal of Sustainable Development of Energy, Water and Environment Systems, 11(2), 1-25. https://doi.org/10.13044/j.sdewes.d10.0436

Riyal, A., Kumar, G., Sharma, D. K., Gupta, K. D., & Srivastava, G. (2022). Blockchain Tree Powered Green Communication for Efficient and Sustainable Connected Autonomous Vehicles. IEEE Transactions on Green Communications and Networking, 6(3), 1428-1437. https://doi.org/10.1109/TGCN.2022.3166104

Sarkodie, S. A., & Owusu, P. A. (2020). Bibliometric analysis of water–energy–food nexus: Sustainability assessment of renewable energy. Current Opinion in Environmental Science & Health, 13, 29-34. https://doi.org/10.1016/j.coesh.2019.10.008

Schletz, M., Cardoso, A., Prata Dias, G., & Salomo, S. (2020). How Can Blockchain Technology Accelerate Energy Efficiency Interventions? A Use Case Comparison. Energies, 13(22), 5869. https://doi.org/10.3390/en13225869

Sharma, A., Tyagi, R., Verma, A., & Paul, A. (2022). Review on Digitalisation and Artificial Intelligence in Human Resource Function of Energy Sector. Water and Energy International, 65(2), 38-46. https://www.researchgate.net/publication/361213725_Review_on_Digitalisation_and_Artificial_Intelligence_in_Human_Resource_Function_of_Energy_Sector

Shishehgarkhaneh, M. B., Moehler, R. C., & Moradinia, S. F. (2023). Blockchain in the Construction Industry between 2016 and 2022: A Review, Bibliometric, and Network Analysis. Smart Cities, 6(2), 819-845. https://doi.org/10.3390/smartcities6020040

Shojaei, A., Ketabi, R., Razkenari, M., Hakim, H., & Wang, J. (2021). Enabling a circular economy in the built environment sector through blockchain technology. Journal of Cleaner Production, 294, 126352. https://doi.org/10.1016/j.jclepro.2021.126352

Siyal, A. A., Junejo, A. Z., Zawish, M., Ahmed, K., Khalil, A., & Soursou, G. (2019). Applications of Blockchain Technology in Medicine and Healthcare: Challenges and Future Perspectives. Cryptography, 3(1), 3. https://doi.org/10.3390/cryptography3010003

Soini, K., & Birkeland, I. (2014). Exploring the scientific discourse on cultural sustainability. Geoforum, 51, 213-223. https://doi.org/10.1016/j.geoforum.2013.12.001

Stanef-Puică, M.-R., Badea, L., Şerban-Oprescu, G.-L., Șerban-Oprescu, A.-T., Frâncu, L.-G., & Crețu, A. (2022). Green Jobs –A Literature Review. International Journal of Environmental Research and Public Health, 19(13), 7998. https://doi.org/10.3390/ijerph19137998

Sulich, A., & Sołoducho-Pelc, L. (2022). Changes in Energy Sector Strategies: A Literature Review. Energies, 15(19), 7068. https://doi.org/10.3390/en15197068

Suta, A., & Tóth, Á. (2023). Systematic review on blockchain research for sustainability accounting applying methodology coding and text mining. Cleaner Engineering and Technology, 14, 100648. https://doi.org/10.1016/j.clet.2023.100648

Tesfamicael, A. D., Liu, V., Mckague, M., Caelli, W., & Foo, E. (2020). A Design for a Secure Energy Market Trading System in a National Wholesale Electricity Market. IEEE, 8, 132424-132445. https://doi.org/10.1109/ACCESS.2020.3009356

Tian, Z., Zhong, R. Y., Vatankhah Barenji, A., Wang, Y. T., Li, Z., & Rong, Y. (2021). A blockchain-based evaluation approach for customer delivery satisfaction in sustainable urban logistics. International Journal of Production Research, 59(7), 2229-2249. https://doi.org/10.1080/00207543.2020.1809733

Treleaven, P., Gendal Brown, R., & Yang, D. (2017). Blockchain Technology in Finance. Computer, 50(9), 14-17. https://doi.org/10.1109/MC.2017.3571047

Truby, J. (2018). Decarbonizing Bitcoin: Law and policy choices for reducing the energy consumption of Blockchain technologies and digital currencies. Energy Research & Social Science, 44, 399-410. https://doi.org/10.1016/j.erss.2018.06.009

Truby, J., Brown, R. D., Dahdal, A., & Ibrahim, I. (2022). Blockchain, climate damage, and death: Policy interventions to reduce the carbon emissions, mortality, and net-zero implications of non-fungible tokens and Bitcoin. Energy Research & Social Science, 88, 102499. https://doi.org/10.1016/j.erss.2022.102499

Tsao, Y.-C., & Thanh, V.-V. (2021). Toward sustainable microgrids with blockchain technology-based peer-to-peer energy trading mechanism: A fuzzy meta-heuristic approach. Renewable and Sustainable Energy Reviews, 136, 110452. https://doi.org/10.1016/j.rser.2020.110452

Varavallo, G., Caragnano, G., Bertone, F., Vernetti-Prot, L., & Terzo, O. (2022). Traceability Platform Based on Green Blockchain: An Application Case Study in Dairy Supply Chain. Sustainability, 14(6), 3321. https://doi.org/10.3390/su14063321

Varriale, V., Cammarano, A., Michelino, F., & Caputo, M. (2020). The Unknown Potential of Blockchain for Sustainable Supply Chains. Sustainability, 12(22), 9400. https://doi.org/10.3390/su12229400

Veit, D. J., & Thatcher, J. B. (2023). Digitalization as a problem or solution? Charting the path for research on sustainable information systems. Journal of Business Economics, 93(6-7), 1231-1253. https://doi.org/10.1007/s11573-023-01143-x

Vranken, H. (2017). Sustainability of bitcoin and blockchains. Current Opinion in Environmental Sustainability, 28, 1-9. https://doi.org/10.1016/j.cosust.2017.04.011

Wang, Q., & Su, M. (2020). Integrating blockchain technology into the energy sector – from theory of blockchain to research and application of energy blockchain. Computer Science Review, 37, 100275. https://doi.org/10.1016/j.cosrev.2020.100275

Wang, S., Ouyang, L., Yuan, Y., Ni, X., Han, X., & Wang, F.-Y. (2019). Blockchain-Enabled Smart Contracts: Architecture, Applications, and Future Trends. IEEE Transactions on Systems, Man, and Cybernetics: Systems, 49(11), 2266-2277. https://doi.org/10.1109/TSMC.2019.2895123

Wilkinson, S., Hojckova, K., Eon, C., Morrison, G. M., & Sandén, B. (2020). Is peer-to-peer electricity trading empowering users? Evidence on motivations and roles in a prosumer business model trial in Australia. Energy Research & Social Science, 66, 101500. https://doi.org/10.1016/j.erss.2020.101500

Wodnicka, M. (2019). Technologie blockchain przyszłością logistyki. Zeszyty Naukowe Małopolskiej Wyższej Szkoły Ekonomicznej w Tarnowie, 41(1), 43-54. https://doi.org/https://doi.org/10.25944/znmwse.2019.01.4354 (in Polish).

Wodnicka, M. (2020). Sharing economy – usługi logistyczne – wzrost gospodarczy. Nierówności Społeczne a Wzrost Gospodarczy, 61(1), 227-237. https://doi.org/10.15584/nsawg.2020.1.16 (in Polish).

Wu, S. R., Shirkey, G., Celik, I., Shao, C., & Chen, J. (2022). A Review on the Adoption of AI, BC, and IoT in Sustainability Research. Sustainability, 14(13), 7851. https://doi.org/10.3390/su14137851

Xu, W., Yan, W., Song, B., & He, J. (2023). Blockchain adoption and strategic contracting in a green supply chain considering market segmentation. Industrial Management & Data Systems, 123(10), 2704-2732. https://doi.org/10.1108/IMDS-02-2023-0080

Yahaya, A. S., Javaid, N., Khalid, R., Imran, M., & Guizani, M. (2020). A Blockchain-based Privacy-Preserving Mechanism with Aggregator as Common Communication Point. *Proceedings of IEEE International Conference on Communications (ICC),* Dublin, Ireland, 1-6. https://doi.org/10.1109/ICC40277.2020.9149213

Yang, Z., Zhu, C., Zhu, Y., & Li, X. (2023). Blockchain technology in building environmental sustainability: A systematic literature review and future perspectives. Building and Environment, 245, 110970. https://doi.org/10.1016/j.buildenv.2023.110970

Yildizbasi, A. (2021). Blockchain and renewable energy: Integration challenges in circular economy era. Renewable Energy, 176, 183-197. https://doi.org/10.1016/j.renene.2021.05.053

Yomboi, J., Majeed, M., Asiedu, E., Nangpiire, C., Alhassan, F., & Manu, V. (2024). Green Blockchain Technology for an Eco-Friendly Environment. In C. Mohan, S. Jeet, S. Dixit & S.A. Carabineiro (Eds.), *Exploring Waste Management in Sustainable Development Contexts* (pp. 219-233). IGI Global. https://doi.org/10.4018/979-8-3693-4264-0.ch015

Yontar, E. (2023). Challenges, threats and advantages of using blockchain technology in the framework of sustainability of the logistics sector. Turkish Journal of Engineering, 7(3), 186-195. https://doi.org/10.31127/tuje.1094375

Zha, D.-S., Feng, T.-T., Gong, X.-L., & Liu, S.-Y. (2022). When energy meets blockchain: A systematic exposition of policies, research hotspots, applications, and prospects. International Journal of Energy Research, 46(3), 2330-2360. https://doi.org/10.1002/er.7398

Zhang, W. F., Sun, H. F., Zhang, Y. D., Tang, R. J., Wang, X. M., Ma, Z., Li, X., & Huang, L. F. (2022). A Consensus Algorithm for Consortium Chain with Tree Based Master-Slave Multi-Chain Architecture. Tien Tzu Hsueh Pao / Acta Electronica Sinica, 50(2), 257-266. https://doi.org/10.12263/DZXB.20201212

Zhao, X. (2022). From Tradition to Innovation: How Intelligent Technology Empowers Educational Evaluation. *Proceedings of the 8th International Conference on Frontiers of Educational Technologies (ICFET),* New York, USA, 36-40. https://doi.org/10.1145/3545862.3545868

Zhou, Y. (2024). Natural resources and green economic growth: A pathway to innovation and digital transformation in the mining industry. Resources Policy, 90, 104667. https://doi.org/10.1016/j.resourpol.2024.104667

Łukasz Jarosław KOZAR • Monika WODNICKA

BLOCKCHAIN W ENERGETYCE: PRZEGLĄD LITERATURY W KONTEKŚCIE ZRÓWNOWAŻONEGO ROZWOJU

STRESZCZENIE: Artykuł ma dwa równorzędne cele badań. Pierwszym celem badań jest identyfikacja kluczowych obszarów badawczych poruszanych w publikacjach naukowych nawiązujących jednocześnie do problematyki blockchain, energetyki oraz zrównoważonego rozwoju. Z kolei wyodrębnienie zielonych obszarów badawczych w tych publikacjach stanowi drugi cel badań. Wskazane cele badań zostały osiągnięte na podstawie przeglądu bibliometrycznego 205 publikacji naukowych z lat 2017-2023 (baza danych Scopus). Za pomocą systematycznego przeglądu literatury zidentyfikowano 25 różnych kluczowych obszarów badawczych. Z kolei klasyczny przegląd literatury pozwolił na wyodrębnienie 18-tu zielonych obszarów badawczych (m.in. green blockchain). Jednocześnie żadna zielona kwestia nie znalazła się wśród zidentyfikowanych kluczowych obszarów badawczych. Rezultaty mogą stanowić inspirację dla badaczy poszukujących luk badawczych wokół kwestii blockchain i zrównoważonego rozwoju. Wśród zaleceń dla interesariuszy zwrócono uwagę m.in. na konieczność dalszych badań wokół technologii blockchain, opracowanie ram regulacyjnych, czy też kwestie edukacyjne.

SŁOWA KLUCZOWE: blockchain, energetyka, zielony blockchain, zrównoważony rozwój

DOI: 10.34659/eis.2024.90.3.866