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Review

# Smart grid and blockchain: Bibliometric analysis

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**Abstract:** The interest in smart grids and new technologies is growing around the world. Countries are investing in the development of new technologies that will help achieve environmental goals, energy supply efficiency, improve energy efficiency and increase consumer involvement in the energy generation. One of such technology is a blockchain. It is believed that the blockchain, combined with a smart grid, provides an opportunity to integrate the activities of all stakeholders, including: generators, distributors and consumers of electricity. The aim of the article is to identify the key research areas discussed by the researchers of both the smart grid and the blockchain issues. An analysis of the Scopus database from 2015 to 2023 was conducted. Using a created bibliometric query, a systematic literature review was conducted. 476 scientific publications relating to the issues addressed were identified. Using the VOSviewer software, a bibliometric analysis was performed using the author's keywords. The bibliometric maps obtained allowed for the identification of key research areas. The article also presents potential future directions of scientific considerations, which should be focused on the issue of green smart grid and green blockchain. The results presented in the article can inspire researchers looking for research gaps or describing the current state of knowledge in the field of the smart grid and the blockchain issues.

**Keywords:** blockchain; energy sector; green transition; new technology; smart grid

## 1. Introduction

The development of the smart grid is identified with the process of transitioning from the energy based on conventional sources to the renewable energy sources. The term smart grid mainly refers to an improved or efficient power grid that allows two-way flow of information and electricity. Current changes in the energy sector are stimulated by various factors. Research in this area pays particular attention to the development of technology, increased environmental awareness of society and regulatory pressure towards sustainable development (Kozar and Paduszyńska, 2021; Kozar and Sulich, 2023a; Wodnicka, 2023). The management of energy infrastructure and resources in such a way as to be both economical, efficient, and reliable access to clean energy for all interested participants in the market is the main goal set for the smart grid.

Currently, the smart grid is undergoing a transformation to a decentralized topology from a centralized form (Mollah et al., 2021) due to the development of prosumer energy. Influenced by the development of prosumer energy, all elements of the energy value chain such as generation, transmission and distribution, and energy trading need to be changed. The smart grids can bring many benefits, which can be grouped from the point of view of different groups of energy market participants. These include consumers/consumers, operators/producers, or various government bodies.

Numerous researchers emphasize the importance of implementing blockchain

technology in various areas and processes including the smart grids due to its important features (automation, immutability, functionality, decentralization, security) (Dong et al., 2018; Pop et al., 2018; Wodnicka, 2019). However, some researchers believe that in many of the early articles written on this topic, there is no systematic analysis of the impact of blockchain technology on the smart grid decentralization (Aderibole et al., 2020). These analyses and studies mainly refer to the conceptual and general application of blockchain technology in smart grids. These research papers are also dominated by the presentations of technical solutions related to the smart grid and the blockchain.

The blockchain technology in the energy sector enables automated data exchange and stores tamper-proof information on energy consumption (Gai et al., 2019). It also secures the financial settlement between energy suppliers and consumers by executing complex energy transactions. In addition, the blockchain allows each product to be tracked transparently and reliably at all stages of the process.

The use of the blockchain and the smart grid in the energy market is justified. These technologies can contribute to the emergence of new innovative energy services, better exchange, and processing of the information between grid actors, including prosumers, and better management and stewardship of energy resources. As an example, electric vehicles can be used for energy storage and delivery in addition to transportation. Nowadays, the cooperation between the electric vehicles and the grid should also ensure that interactions are established for energy exchange (Aderibole et al., 2020; Teimoori and Yassine, 2022).

The research conducted and presented in this article aimed to identify key research areas addressed in academic articles on both the smart grid and the blockchain issues. To achieve the set research goal, a literature review was conducted using the systematic literature review (SLR) method. Some scientific publications from the Scopus database from 2015–2023 were explored. In accordance with the requirements of the Scopus database, the author's research query Q1 was formulated (it is described in the Materials and methods section). The obtained research results were visualized in the form of the generated bibliometric maps using the VOSviewer software (version 1.6.20).

The structure of the article includes four sections, which are closely interrelated. In the introduction, the issues of the research problem undertaken are presented, explaining their significance in contemporary scientific discourse. In addition, the purpose of the research undertaken is indicated. The second part presents the schedule of the analyses undertaken and describes the research activities undertaken, as well as the content of the bibliometric inquiry and materials. The third part includes data visualizations on bibliometric maps and a synthetic description of the obtained results. The article ends with a discussion of the issues undertaken and conclusions.

## 2. Materials and methods

The research presented in this article was conducted in the period March-June 2024. It was carried out in three stages, during which significant research activities were carried out. **Figure 1** shows the adopted research stages, which served to achieve the research objective presented in the introduction.

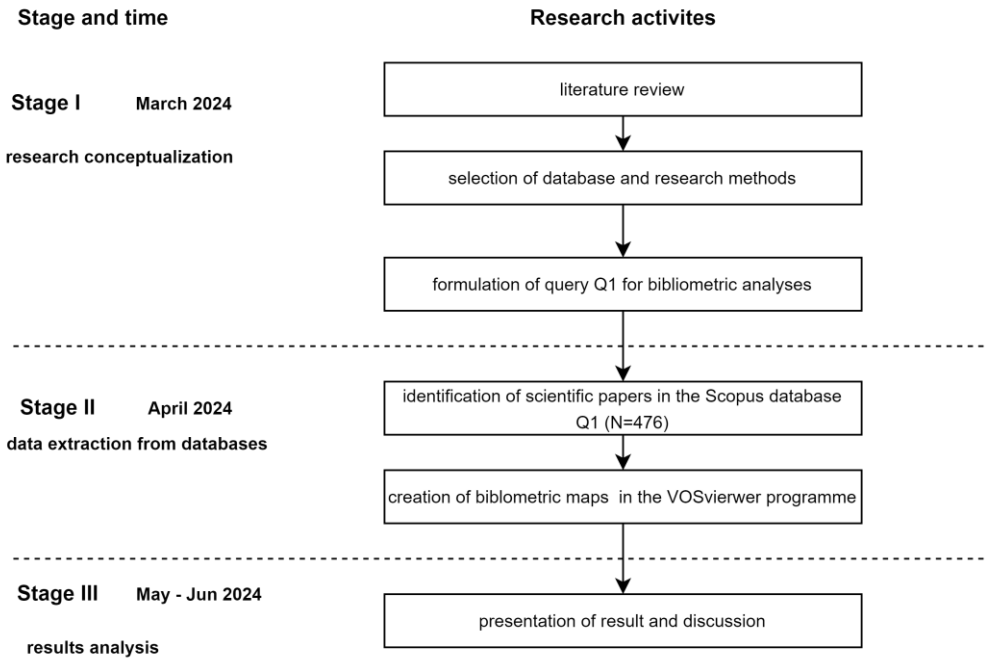


**Figure 1.** Research procedure stages and timeline.
Source: Authors' elaboration in VOSviewer software (1.6.20 version).

The conceptualization of the research was the first stage of the study, which was aimed at a general review of scientific publications in the field of the smart grid and the blockchain issues. This stage began the scientific considerations undertaken in this article. Based on the review of some selected scientific publications from the Scopus database, a selection of research methods, techniques and tools was made and a Q1 bibliometric query was constructed. The created bibliometric query is presented in **Table 1** Due to the adopted research assumptions aimed at the bibliometric analysis, the SLR method was chosen. A Systematic Literature Review (SLR) is a research methodology that involves collecting, identifying and critically analyzing available research (Pati and Lorusso, 2018). Using a systematic procedure, it allows the collection of relevant knowledge in a given field and the determination of the state of that knowledge through the identification of research gaps (Carrera-Rivera et al., 2022).

**Table 1.** Search query syntax details.

| Symbol | Query Syntax | No. Results |
|---|---|---|
| Q1 | TITLE-ABS-KEY ("smart grid" AND blockchain) AND PUBYEAR > 2015 AND PUBYEAR < 2024 AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re")) AND (LIMIT-TO (LANGUAGE, "English" )) | 476 |

Source: Authors' elaboration.

In the second stage of the research, based on bibliometric query Q1, the titles, abstracts and keywords of scientific publications included in the Scopus database, in which there was a reference to the smart grid and the blockchain issues, were searched (**Table 1**). The query omitted publications written in 2024. This is due to the good

practice of the bibliometric analysis. It can be seen in the literature that researchers, for the sake of transparency and comparability of their studies in the future, do not take publications from the year in which the survey is conducted into the bibliometric analyses (Kozar and Sulich, 2023b; Sulich and Kozar, 2023). A search of the Scopus database identified 476 scholarly publications in the field of the subject matter undertaken, which were subjected to a control analysis. This analysis aimed to search for publications that are duplicative or do not have assigned authors. As a result of the analysis, it was found that all the identified 476 scientific publications met the requirements for further analysis. The publications accepted for the analysis included articles (396) and scientific reviews (80). Criteria for extracting scientific publications from the Scopus database are presented in **Table 2**.

**Table 2.** Criteria for extracting scientific publications from the Scopus database.

| Criteria | Details |
|---|---|
| Database | Scopus |
| Search area | Article title, Abstract, Keywords—TITLE-ABS-KEY |
| Topics | Smart grid and blockchain: bibliometric analysis |
| Time span | < 2024 |
| Document type | Articles (396), Review (80) |
| Publication stage | Final (476) |
| Source type | Journal (476) |
| Language | English (476) |

Source: Authors' elaboration.

The next step taken was to identify author keywords. The analysis indicated the need for a procedure to standardize authoritative keywords due to their different forms of writing. This procedure was applied to the keywords that: were with linguistic errors, occurred in both plural and singular, their spelling was in different versions of English (English and American). Abbreviations of author keywords were also replaced with the full name of the author word in question. As a result, from 1110 keywords, 963 keywords were obtained for further analysis. Based on these, it was possible to create bibliometric maps in the VOSviewer software and proceed to the third stage of the research (analysis of the results obtained).

VOSviewer software was used for the analyses because this software uses input from the Scopus database. It is statistical software that identifies relationships in the networks of publications and their citations and keywords. The elements in these networks can be related, for example through co-authorship, co-occurrence, citation, bibliographic coupling. The use of statistical programs in research analysis makes it possible to identify research trends and links between citations in the area of the research problem under study (Kirby, 2023). VOSviewer software, within its capabilities, allows the creation of bibliometric maps and the construction of tables with bibliometric data, which facilitates the visualization of data (Kozar and Wodnicka, 2024). The use of statistical programs in research analysis makes it possible to identify research trends and links between citations in the area of the research problem under study.

## 3. Results

This part of the article presents the results of the obtained results in the form of bibliometric maps, which were generated in the VOSviewer software. To indicate the main research areas in the analyzed articles, the focus was on author keywords. The minimum number of co-occurrences of authorial keywords was set at ten. The indicated criteria were met by 32 authorial keywords. These words were visualized on a bibliometric map prepared using VOSviewer software (**Figure 2**).

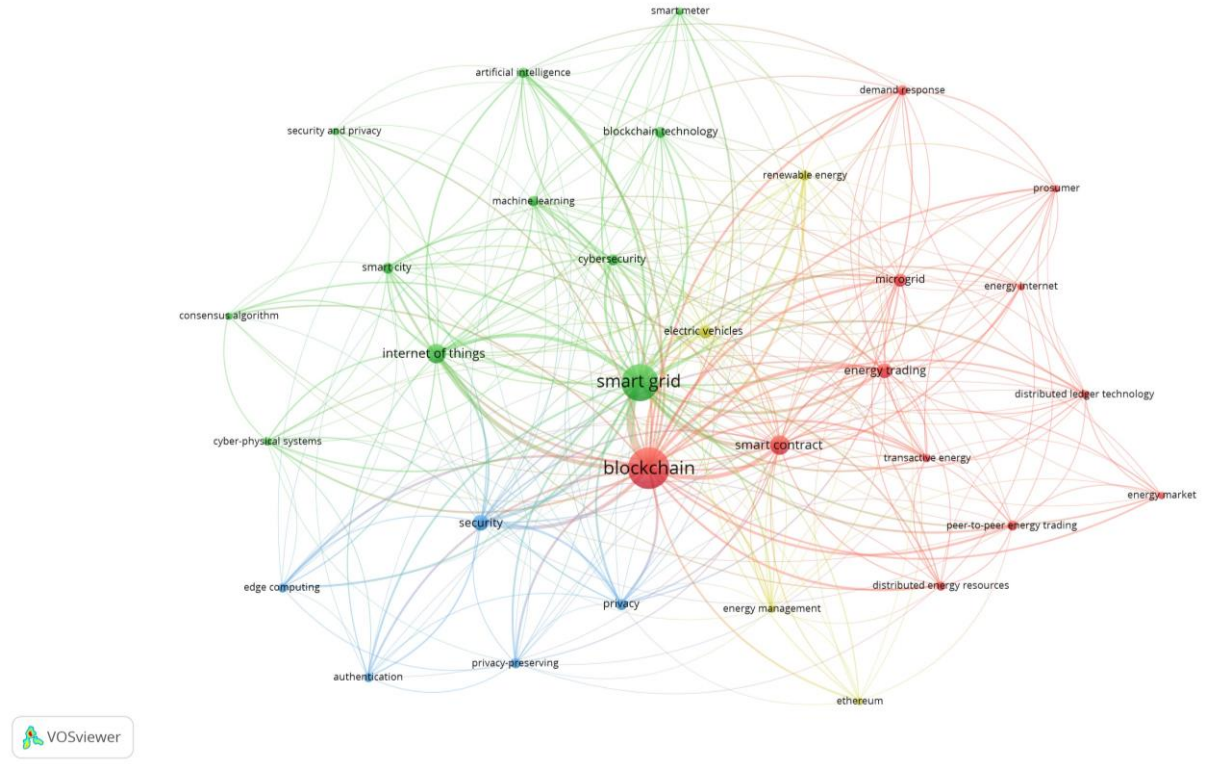


**Figure 2.** Author keywords co-occurrences in full counting method of Q1 results.
Source: Authors' elaboration in VOSviewer software (1.6.20 version).

**Table 3.** Clusters of author's keywords co-occurrences visible in **Figure 2**.

| Cluster | Color | Keywords |
|---|---|---|
| 1 | Red | blockchain (*O* = 319, *L* = 30); demand response (*O* = 20, *L* = 17); distributed energy resources (*O* = 15, *L* = 15); distributed ledger technology (*O* = 14, *L* = 16); energy internet (*O* = 11, *L* = 14); energy market (*O* = 11, *L* = 11); energy trading (*O* = 41, *L* = 23); microgrid (*O* = 32, *L* = 23); peer-to-peer energy trading (*O* = 20, *L* =16), prosumer (*O* = 11, *L* = 14); smart contract (*O* = 70, *L* = 31); transactive energy (*O* = 13, *L* = 19) |
| 2 | Green | artificial intelligence (*O* = 21, *L* = 20); blockchain technology (O = 26, L = 17); consensus algorithm (O = 10, L = 9); cyber-physical systems (*O* = 13, *L* = 16); cyber security (*O* = 24, *L* = 22); internet of things (*O* = 75, *L* = 27); machine learning (*O* = 21, *L* = 22); security and privacy (*O* = 10, *L* = 10); smart city (*O* = 24, *L* = 19); smart grid (*O* = 256, *L* = 31); smart meter (*O* = 10, *L* = 15) |
| 3 | Blue | authentication (*O* = 18, *L* = 13); edge computing (*O* = 18, *L* = 14); privacy (*O* = 24, *L* = 21); privacy-presering (*O* = 21, *L* = 17); security (*O* = 50, *L* = 25) |
| 4 | Yellow | electric vehicles (*O* = 33, *L* = 25); energy management (*O* = 11, *L* = 17); ethereum (*O* = 10, *L* = 11); renewable energy (*O* = 21, *L* = 20) |

*O*—number of co-occurrences, *L*—number of links.
Source: Authors' elaboration.

Each author word was assigned to one of four clusters by the VOSviewer

software. A measure of occurrences (O) and links (L) was used to present quantitative bibliometric data. The occurrences measure used indicated that the blockchain (red cluster), the smart grid (green cluster), the security (blue cluster), the electric vehicles (yellow cluster) were the most frequent author words in the analyzed scientific publications. **Table 3** presents the author keywords, which are arranged alphabetically in each cluster.

The next step in the analysis undertaken was to generate a bibliometric map for the author's smart grid keyword (**Figure 3**). As it can be seen the smart grid is associated with all the indicated keywords presented in **Table 3**.

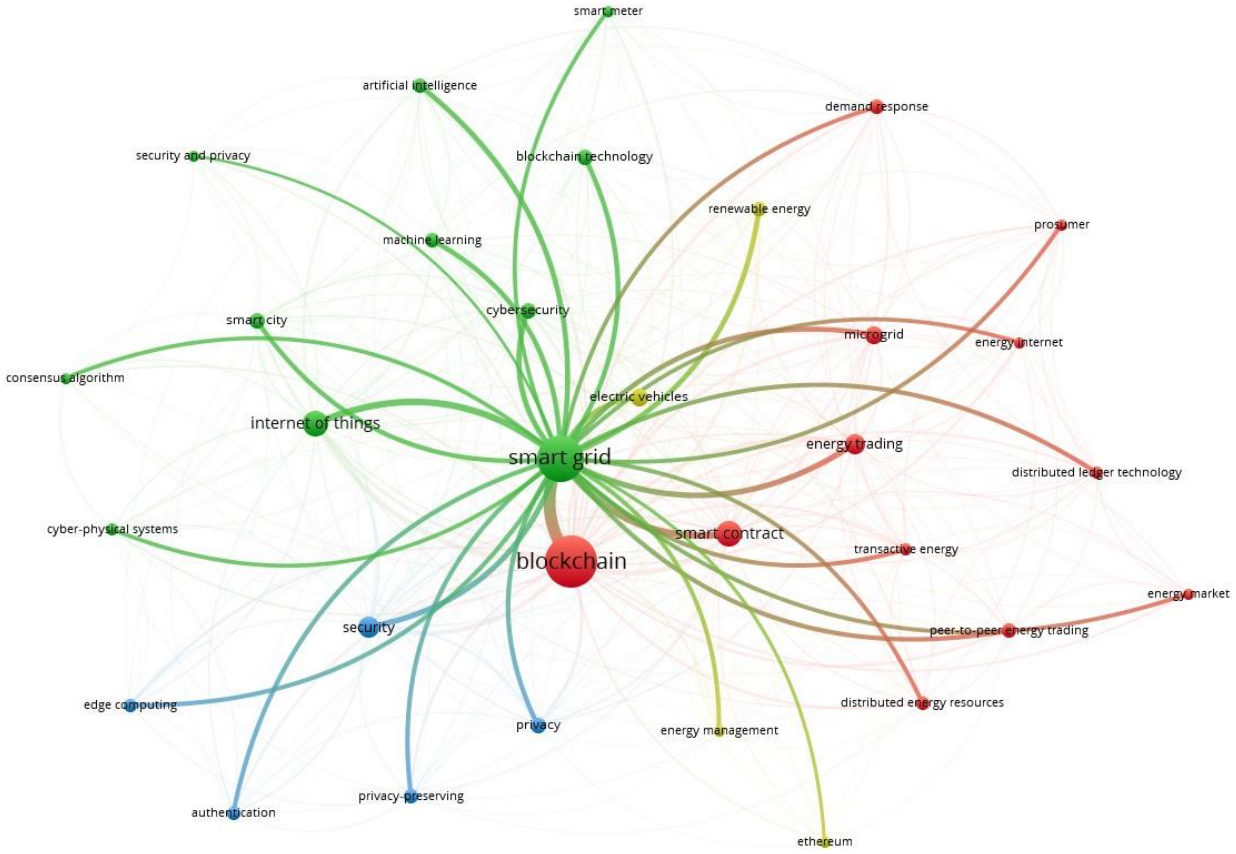


**Figure 3.** Keyword "smart grid" relations with other keywords.
Source: Authors' elaboration in VOSviewer software (1.6.20 version).

To show the ongoing changes over the time of the scientific research undertaken on the subject under discussion, an overlay bibliometric map was generated using the VOSviewer software (**Figure 4**). As can be seen from the presented map, the most current areas of research combining the issues of the smart grid and the blockchain are internet of things, smart contract, energy market, privacy-preserving, security, machine learning, artificial intelligence, peer-to-peer energy trading, cybersecurity, authentication. These areas are marked in bright color on the map.

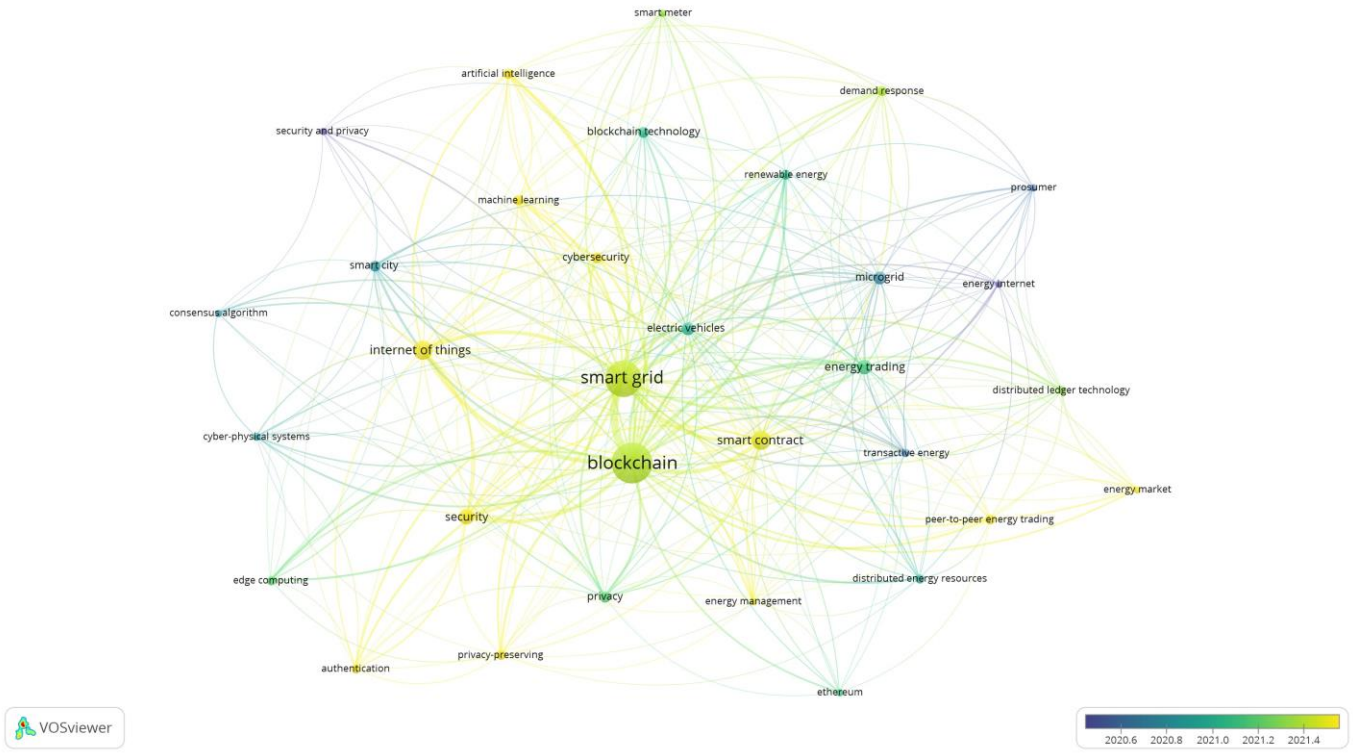


**Figure 4.** Overlay map of the author's keywords co-occurrences.
Source: Authors' elaboration in VOSviewer software (1.6.20 version).

The results of the analysis, presented in **Figures 2–4** and **Table 3**, will be discussed later in this article.

## 4. Discussion and conclusion

The analyses conducted showed that some articles taken for the bibliometric analyses presented results from bibliometric studies. The researchers used the Scopus database (Rejeb et al., 2022) or Web of Science (Ante et al., 2021; Kamran et al., 2020; Wang et al., 2021) for their analyses. The cases of using both databases simultaneously are also evident (Biegańska, 2022).

The analyzed articles addressed the issue of the smart grid and the blockchain to varying degrees. In some constructed bibliometric queries, in addition to using the words the smart grid and the blockchain, reference was made to the intranet of things and energy to show the relationship between the two (Biegańska, 2022). In some publications there was a lack of reference to smart grid and blockchain in the query directed to the analyzed databases. The authors only referred to this issue in the discussion, pointing out the importance of the smart grid and the blockchain as an element supporting smart city management (Rejeb et al., 2022).

In addition, the analysis also shows that some researchers referred only to the blockchain in their bibliometric queries. They mainly focused their analysis on explaining the links between blockchain technology and energy by describing the use of this technology in energy (Ante et al., 2021; Wang et al., 2021) or the use of this technology on the Internet of Things (Kamran et al., 2020). Other authors, on the other

hand, in their bibliometric inquiries referred only to the smart grid highlighting areas such as the use of artificial intelligence in the smart grids in the context of sustainable development (Lampropoulos, 2023) or emphasized its social dimension (Bayindir et al., 2023). Hence, the study presented here is distinguished by the content of the bibliometric inquiry, which resulted in new quality data presented in the bibliometric maps.

The energy transition and the associated development of distributed energy and the development of new technologies is inspiring many researchers (Çolak and Irmak, 2023; Li et al., 2023; Mololoth et al., 2023). It is recognized that around the smart grid, the blockchain technology has a great opportunity to be used (Aklilu and Ding, 2022; Khan and Masood, 2022). The issue of the cyber-physical layer, for example, is pointed out here (Musleh et al., 2019).

The scope of the smart grid and the blockchain integration covers several areas. One is the use of smart contracts to help manage demand (Said, 2023), production (Li and Gong, 2022), and energy distribution (Khan and Masood, 2022; Kumar et al., 2020). The blockchain technology is expected to help balance energy supply and demand at the smart grid level by continuously tracking the distribution of energy sales and demand (Gai et al., 2019). It is expected to improve peer-to-peer energy trading between prosumers in the energy market (Kumari et al., 2022) using smart contracts (Honari et al., 2023). It is becoming important to integrate all prosumers (Hua et al., 2022), including all electric vehicles into the smart grid, which the blockchain technology can help with (Fakhar et al., 2023; Hasan et al., 2022).

Some researchers also emphasize that the use of smart grids and blockchain in the area of distributed renewable resources will have an impact on the evolution and development of the Internet of Energy market (Miglani et al., 2020). Various challenges are also recognized that need to be addressed to integrate these two technologies (Alladi et al., 2019). These challenges were identified in this study as emerging areas of research. These include privacy-preserving (Mahmood et al., 2023; Oberko et al., 2023; Zhao et al., 2023), security (Kalbantner et al., 2021; Minoli and Occhiogrosso, 2018), peer-to-peer energy trading (Alsolami et al., 2023; Moniruzzaman et al., 2023), cybersecurity (Awan et al., 2023; Mazhar et al., 2023), authentication (Bagga et al., 2022; Lee et al., 2023).

An important, but still invisible in the bibliometric map obtained, area of future research should be issues such as the green smart grid (Oad et al., 2023), or the green blockchain (Hassan et al., 2022). These issues are already emerging in academic research, but there is a lack of demonstration of these areas in the author's keywords that were analyzed in the study. Hence, analysis related to green transformation and the place of the smart grid and the blockchain in it has become an important challenge for future researchers.

The research carried out in this article proves that the stated research objective of identifying the main areas of research undertaken by the researchers in the smart grid and the blockchain issues has been achieved. In addition, the research conducted is unique, indicating the Q1 bibliometric query constructed. As the analyses conducted in this article has shown, this query is different from the previous research.

A limiting factor of the present research may be the choice of the database, which was limited to the Scopus database. Nevertheless, this procedure was justified given

that the Scopus database is one of the largest peer-reviewed databases of multidisciplinary research publications (Ben Youssef and Mejri, 2023). The content of bibliometric query Q1, which referred to the smart grid and the blockchain and also simultaneously applied various exclusions (regarding publication language, analysis period, source type, publication stage, document type), may also be a limitation.

**Conflict of interest:** The author declares no conflict of interest.

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