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Blockchain Technology Applications for Decarbonization: A Bibliometric Review

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***Abstract* – The integration of decentralized and digital technologies like blockchain in sectors that aim to fulfil certain decarbonization goals could be a promising solution to facilitate the transition to climate neutrality. With the aim to construct a comprehensive and systematic bibliometric analysis on the inclusion of blockchain technology in renewable energy, transport (electric vehicles) and agri-food industry, this paper provides an in-depth analysis of existing studies on these topics to identify future research opportunities. Using R-studio, Web of Science and Scopus data were analysed and visualized. The results of this study indicate growth of the publication count throughout the years. This research shows that the most productive countries are China and India, although the average citations per article is higher in United States of America and United Kingdom. Trend topics, thematic evaluation and co-occurrence network from this study suggest that the application of blockchain technology in analysed sectors should be combined with other digital solutions like Internet of Things and artificial intelligence to increase security, facilitate systems' management and assist in policy planning. The identified research gaps are connected to blockchain technology and renewable energy storage systems (e.g., hydrogen), materials used in electric vehicles' batteries and circularity (including life cycle and recycling) in the agri-food sector and other studied sectors.**

***Keywords* – Agri-food; blockchain; decarbonization; electric vehicles; renewable energy.**

1. INTRODUCTION

With the common commitment of reaching climate neutrality by 2050 [1], challenges that must be overcome even now are unprecedented. Many sectors will have to change the operational agenda [2] while maintaining certain self-sufficiency. One of the first sectors that must be transformed according to European Union's (EU) laws, is energy [3].

Renewable energy generation globally is increasing as confirmed by International Renewable Energy Agency in 2023 report for the last decade [4]. Meanwhile the upcoming phase-out of internal combustion engines in the EU is complemented by adopted Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC (Batteries Regulation) [5] indicating the foreseen increase in electric vehicles. Batteries Regulation requires more efficient use of raw materials in battery production processes, more sustainable raw material sourcing and more circular end-of-life processing [6].

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To further support the cut for reliance on fossil fuels on 2nd February 2024 the European Commission adopted the Industrial Carbon Management Strategy where the battery value chain is underlined as one of the crucial aspects of sustainable transport electrification [7]. To support this Strategic Action Plan on Batteries was developed to ensure that the long-term vision for climate-neutral economy is achieved without sacrificing the sustainable and circular use of raw materials [8].

In addition to focusing on sustainable energy, it is crucial to tackle the significant environmental impacts linked to the food sector, which is creating the biggest consumption footprint according to European Commission's Joint Research Centre assessment. Food adds 52 % to the regionalized consumption footprint in the EU countries [9]. Taking into account Farm to Fork Strategy [10] adopted in 2020, sustainable food systems must be created ensuring no negative environmental impact from food production and positive assistance in climate change mitigation.

The transition within the energy and food sector are requiring improved data management, traceability and security. Digital solutions should be introduced to provide the necessary technical assistance. One technology that could facilitate transition to climate neutrality is blockchain which is operating on distributed ledger technology [11]–[13] firstly described by Nakamoto in 2008 [14]. Blockchains are immutable and tamper-proof registers that do not need a central governance entity. The digital transactions are registered securely in blocks via decentralized network of participants (nodes). It is known that blockchain, based on its operating principles, can ensure transparency, traceability, detailed recordings of actions and more important – it cannot be changed by a single member thus reducing the risks of manipulations with data. The nature of blockchain to encode data in series of blocks provides reinforced data integrity [15]. Authors of this study agrees with the opinion stated in previously published articles [16]–[18] that blockchain has the potential to contribute to the implementation of decarbonization goals by promoting the development of digitalization in various sectors of economy, especially for supply chain, smart metering and automatization processes management.

A complete analysis of research on the blockchain technology applications in various sectors (and their associated subtopics) that are involved in the climate neutrality goals has not been presented in the literature. Therefore, the aim of this study is to acknowledge the state-of-the-art for blockchain technology in decarbonization related topics, in particular, renewable energy, electric vehicles and agri-food sector by constructing a comprehensive and systematic bibliometric analysis that would help to determine research gaps for blockchain technology's use to reach climate neutrality.

To provide a detailed description of the topics mentioned the remaining study is constructed as follows – the methodology part explains all keyword searches performed and tools that were used to analyse the data, results and discussion shows both graphical and textual information gathered from bibliometric analysis and compares it to other studies in this field, conclusion provides the overview of the study and future research topics.

2. METHODOLOGY

Web of Science (WoS) and Scopus databases were chosen for keyword searches due to their extensiveness – they are regarded as the two largest comprehensive citation databases worldwide [19], [20]. The bibliometric approach was chosen due to its proven abilities to comprehensively and in detail describe the status of research on the chosen topic [21], [22].

Search was divided in categories (levels of detail) shown in Fig. 1 to provide a comprehensive and detailed overview of the topic. The first categories are 'blockchain' and

'renewable energy', 'blockchain' and 'electric vehicle*' and 'blockchain' and 'agri-food', the second are 'blockchain' and 'renewable energy' and 'storage', 'blockchain' and 'renewable energy' and 'hydrogen', 'blockchain' and 'electric vehicle*' and 'supply chain' etc. The third categories were identified for 'blockchain' and 'renewable energy' and 'blockchain' and 'electric vehicle*' topics and are the 'blockchain' and 'renewable energy' and 'storage' and 'batter*', 'blockchain' and 'electric vehicle*' and 'supply chain' and 'batter*' and 'blockchain' and 'electric vehicle' and 'charging' and 'batter*'. The scope of categories and searches was determined taking into account decarbonization needs in different sectors based on literature research described in introduction and considering the further possible research topics of the authors of this paper. For example, keywords like life cycle and circularity were included only in agri-food sector searches based on the fact that initial search for these keywords in 'blockchain' and 'renewable energy' and 'blockchain' and 'electric vehicle*' topics lead to very few publication results (which is addressed in conclusion section). String operators 'AND' and 'OR' were used to precisely define the keyword combinations for the searches. If the search contained a word that's ending could be diverse (for example, battery and batteries), * was used at the end of the common part of the word. It must be mentioned that the search ('blockchain' OR 'blockchain technology') AND ('electric vehicle*') AND ('supply chain') AND ('batter*') AND ('material*') provided no results thus it is not analysed as other searches but is used to provide future research topics in conclusion.

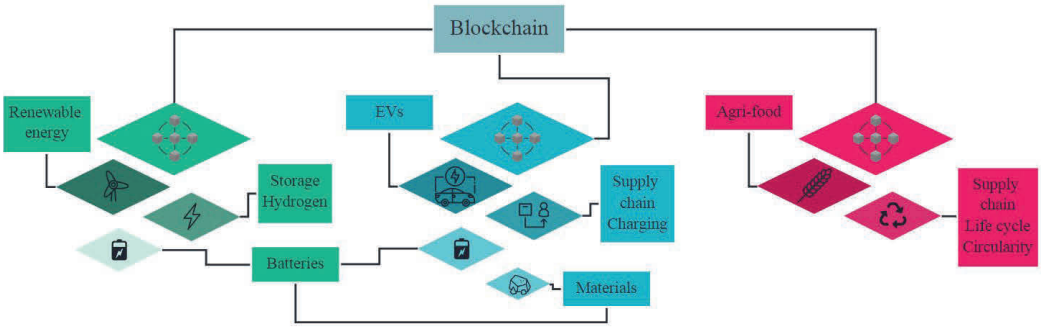

Fig. 1. The categories for performed keyword searches.

Keyword searches performed in WoS and Scopus on blockchain and renewable energy can be seen in Table 1, on blockchain and electric vehicles in Table 2 and on blockchain and agri-food sector in Table 3. For the full schematic overview of the methodology used in this paper, see Fig. 2. 15 of 38 available data analysis parameters were used to provide the most comprehensive and informative yet consolidated description of the research topic. Parameters such as annual scientific production and average citations per year were chosen to describe the quantitative changes in the topics year by year. To indicate the main countries where scientists are working on these topics, various parameters related to the publication's country of origin and the author's affiliation were used. To show the linkage between the keywords, authors and the evolution of the topics in time, parameters like three-field plot, trend topics, thematic evolution and co-occurrence network were used. Bradford's law describes an exponentially decreasing yield when searching for journal references and helps identify the 'core' journals within the topic (journals are divided in zones where zone 1 contains the 'core' journals), while Lotka's law shows the number of publications from authors as an inverse square graph [23].

TABLE 1. KEYWORD SEARCHES ON BLOCKCHAIN AND RENEWABLE ENERGY

No.	Keyword search abbreviation	Full keyword search
1	'blockchain' and 'renewable energy'	('blockchain' OR 'blockchain technology') AND ('renewable energy' OR 'green energy' OR 'clean energy' OR 'sustainable energy')
2	'blockchain' and 'renewable energy' and 'storage'	('blockchain' OR 'blockchain technology') AND ('renewable energy' OR 'green energy' OR 'clean energy' OR 'sustainable energy') AND ('storage')
3	'blockchain' and 'renewable energy' and 'storage' and 'batter*'	('blockchain' OR 'blockchain technology') AND ('renewable energy' OR 'green energy' OR 'clean energy' OR 'sustainable energy') AND ('storage') AND ('batter*')
4	'blockchain' and 'renewable energy' and 'hydrogen'	('blockchain' OR 'blockchain technology') AND ('renewable energy' OR 'green energy' OR 'clean energy' OR 'sustainable energy') AND ('hydrogen')

TABLE 2. KEYWORD SEARCHES ON BLOCKCHAIN AND ELECTRIC VEHICLES

No.	Keyword search abbreviation	Full keyword search
1	'blockchain' and 'electric vehicle*'	('blockchain' OR 'blockchain technology') AND ('electric vehicle*')
2	'blockchain' and 'electric vehicle*' and 'supply chain'	('blockchain' OR 'blockchain technology') AND ('electric vehicle*') AND ('supply chain')
3	'blockchain' and 'electric vehicle*' and 'supply chain' and 'batter*'	('blockchain' OR 'blockchain technology') AND ('electric vehicle*') AND ('supply chain') AND (batter*)
4	'blockchain' and 'electric vehicle*' and 'charging'	('blockchain' OR 'blockchain technology') AND ('electric vehicle*') AND ('charging')
5	'blockchain' and 'electric vehicle*' and 'charging' and 'batter*'	('blockchain' OR 'blockchain technology') AND ('electric vehicle*') AND ('charging') AND ('batter*')

TABLE 3. KEYWORD SEARCHES ON BLOCKCHAIN AND AGRI-FOOD SECTOR

No.	Keyword search abbreviation	Full keyword search
1	'blockchain' and 'agri-food'	('blockchain' OR 'blockchain technology') AND ('agri*' OR 'food')
2	'blockchain' and 'agri-food' and 'supply chain'	('blockchain' OR 'blockchain technology') AND ('agri*' OR 'food') AND ('supply chain')
3	'blockchain' and 'agri-food' and 'life cycle'	('blockchain' OR 'blockchain technology') AND ('agri*' OR 'food') AND ('life cycle')
4	'blockchain' and 'agri-food' and 'circular*'	('blockchain' OR 'blockchain technology') AND ('agri*' OR 'food') AND ('circular*')

In both databases only articles were included to exclude review papers and conference papers as suggested by Öztürk *et al.* [24] to focus on peer-reviewed empirical research and already developed knowledge. As the studied topics are developing only in recent years no limitations to the publication years were set. The data was downloaded in BibTeX (.bib) and Comma Separated Values (.csv) format. Merged files for specific figures were created and duplicates were removed using R in R-studio with 'covert2df' and 'mergeDbSources' functions (if an article is indexed in both databases, where the total number is needed, only one copy is kept to avoid double counting).

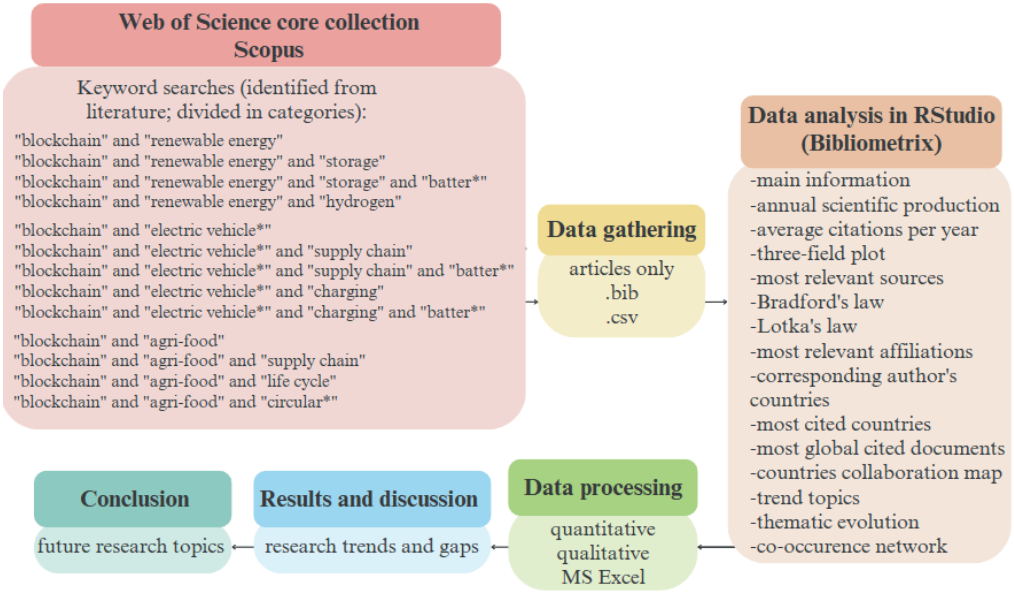

Fig. 2. Research methodology framework.

Data analysis was done in R using Rstudio (version 4.3.3.) – the 'Bibliometrix' library with 'Biblioshiny' package (version 4.0.0.) was used to analyse and visualize data. This interface was created by Dr Massimo Aria from University of Naples Federico II and Dr Corrado Cuccurullo from University of Campania Luigi Vanvitelli in 2017 and is more and more used to provide visual and informative bibliometric analysis of scientific publications [23]. A list of synonyms was uploaded where possible. Data gathered from 'Biblioshiny' was also combined and represented in graphs using MS Excel for Microsoft 365. The representation of WoS or Scopus data (where only one database's data is shown) was chosen on the authors' perception which of the results was more representative of the topic. The data after the in-depth processing is shown in the results section.

3. Results and Discussion

3.1. Main Information

Main information on each keyword search is shown in Annex 1(supplementary file to this article). The table is provided to give an overall insight of the articles found by keyword searches. The first articles on performed searches were published in 2017 and the annual growth rate almost in all cases is positive which indicates that studied topics are relevant and continuing to gain their prevalence. It must be taken into account that all articles until May 2024 were included. Until May 2024 396 articles in WoS and 459 articles in Scopus were published including keywords 'blockchain' and 'renewable energy', without duplicates (meaning that articles indexed in both databases are counted only once, please see Methodology regarding removal of duplicates) it made up to 576 articles (see Fig. 3).

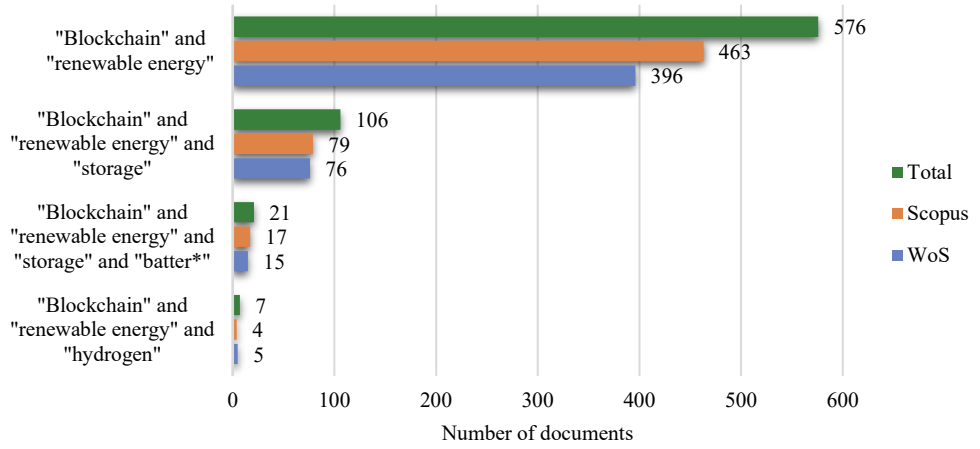

Fig. 3. Number of articles including keywords ‘blockchain’ and ‘renewable energy’.

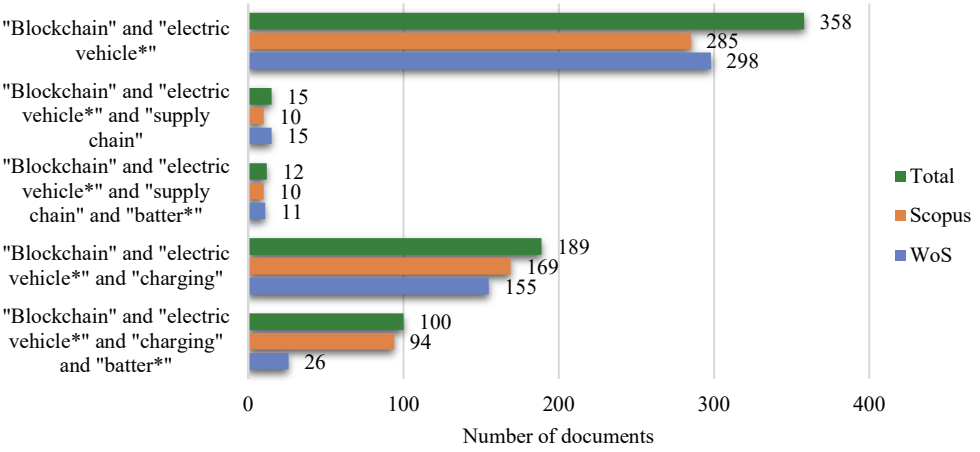

Fig. 4. Number of articles including keywords ‘blockchain’ and ‘electric vehicle*’.

More than 1500 authors have published articles on this topic. On average around 4 co-authors are working together for these publications. On topic ‘blockchain’ and ‘electric vehicle*’ there were 298 articles in WoS and 282 in Scopus (without duplicates 358, see Fig. 4) written by more than 1000 authors. It can be seen that this topic being studied for the same timespan as previous topic is not so widespread – it must be taken into account that renewable energy is much wider subject than electric vehicles. The third group – ‘blockchain’ and ‘agri-food’ is the most popular of the three general topics studied. There have been 964 articles published in WoS and 1057 articles in Scopus (without duplicates 1359, see Fig. 5) with more than 3000 authors participating.

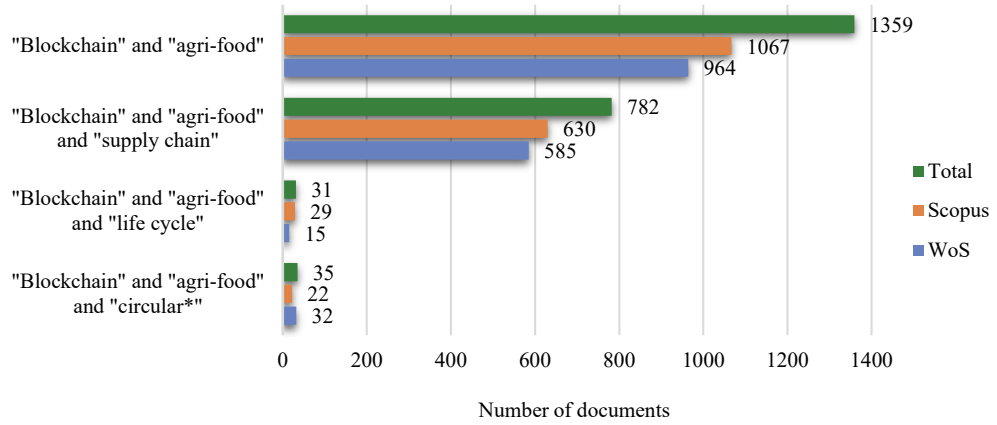

Fig. 5. Number of articles including keywords 'blockchain' and 'agri-food'.

While not being the topic with biggest average citations per document (21.65 in WoS and 26.23 in Scopus) the average age of document is 2.06–2.09 (one of the shortest ages for topics with more than 35 documents published) years indicating that more and more new articles are published every year. It must be highlighted that more complicated and detailed topics like 'blockchain' and 'renewable energy' and 'hydrogen' have average document age of 1.2–1.25 years or 'blockchain' and 'electric vehicle' and 'supply chain' and 'batteries' have average document age of 1.2–1.45 years and are only published since 2021. It can be assumed that these are very new and relatively unexplored topics. The high average citations count per document (36.91 in WoS and 32.55 in Scopus) on topic 'blockchain' and 'agri-food' and 'circular*' must be emphasized to indicate still very rarely studied but important and relevant topic.

3.2. Annual Growth

By analysing the annual growth of the published articles on topic 'blockchain' and 'renewable energy' it can be assessed that since 2022 more than 100 articles each year are indexed in each database pointing to very slow increase in the article count growth. By delving into more detailed topics like 'blockchain' and 'renewable energy' and 'storage' it can be highlighted that since 2021 the average article count has not been increasing rapidly. This could indicate the complexity of integrating blockchain in renewable energy storage systems and (or) the lack of empirical studies in this field. Even more specific searches like 'blockchain' and 'renewable energy' and 'storage' and 'batteries' or 'blockchain' and 'renewable energy' and 'hydrogen' are relatively new topics in the science in general and are not widely studied yet.

Similarly, the annual growth of the published articles on topic 'blockchain' and 'electric vehicles' has equal slow increase, with fewer publications in 2023 and increase in first months of 2024 which can be explained as a study period for this research topic also mentioned by Cui *et al.* and Geng *et al.* [25], [26]. The number of articles on topic 'blockchain' and 'agri-food' (and more detailed keyword search including supply chains) is slowly growing reaching 275 articles in WoS and 310 articles in Scopus in 2023 (including supply chains – 180 articles in WoS and 200 articles in Scopus in 2023).

3.3. Average Total Citations per Year

To explore the previously mentioned average total citations per document, more detailed review for average total citations per year was performed. An example for keyword search 'blockchain' and 'renewable energy' can be seen in Fig. 6. The data indicates that in general articles published in first two years (e.g., in this case 2017 and 2018) in all cases have the highest mean total citations. In the case with keyword searches with renewable energy the articles published in second year are the most cited (because there are specific publications with very high total citation count), but in other cases – the most cited ones are from first year indicating the importance of the first publications on specific topic.

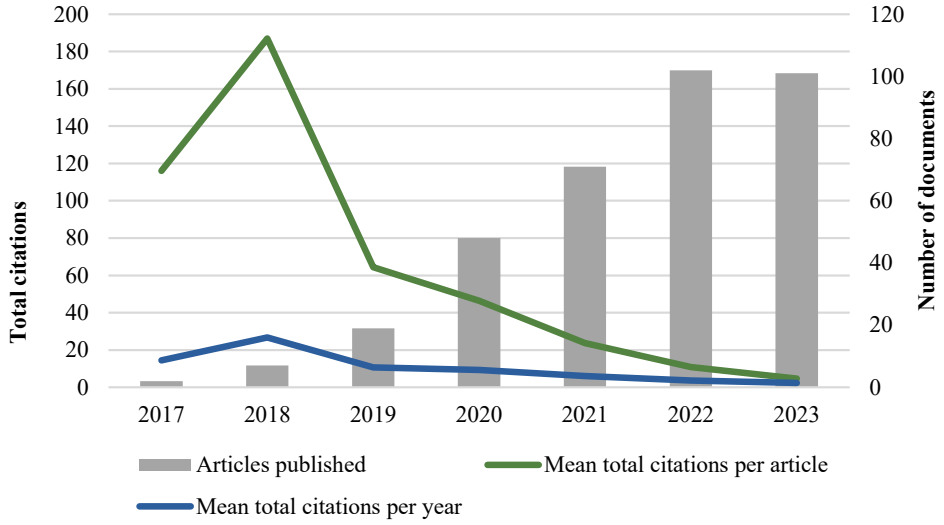

Fig. 6. Average total citations per year (WoS 'blockchain' and 'renewable energy' search).

3.4. Three-Field Plots

The three-field plots showing most cited references, 10 most relevant authors and keywords in their articles were prepared. Example showing results from keyword search on 'blockchain' and 'renewable energy' can be seen in Annex 2 – supplementary file to this article (Fig. 1). Three-field plot function was not able to take into account synonyms. While Mengelkamp *et al*. and Andoni *et al*. publications are used as the main references [27], [28], the most relevant authors are Kumar., Zhang Y. and Zhang X. The main keywords without 'blockchain' and 'renewable energy' are 'smart grid', 'renewable energy sources' and 'energy trading' indicating research focus in authors' publications. For keyword search including also 'storage' the most relevant author is Tanwar S. focusing on energy trading and smart grids. It must be mentioned that Kumar is also the most relevant author in keyword search 'blockchain' and 'electric vehicles' followed by Javaid N. and Wang Y. (see Fig. 2 in Annex 2). The most relevant references are Kang *et al*. and Su *et al*. exploring vehicle-to-grid, privacy and energy trading topics [29], [30]. Keyword search including 'charging' and 'batteries' also delves into topics like energy management and smart cities. The main keywords for topic 'blockchain' and 'agri-food' are sustainability, traceability, supply chain, agriculture and internet of things (see Fig. 3 in Annex 2). The most relevant authors are Kumar., Zhang X. and Li.

3.5. Most Relevant Sources and Bradford's Law

The most relevant scientific journals where articles from keyword searches (with results – more than 35 articles) were published are compiled in Annex 3 (supplementary file to this article). Journals were included in the table only if they were in the top 5 (based on article count – shown as the number for respective journal for respective keyword search) for the specific topic. **Data on article count in the respective journal from WoS is shown on the left side of the cell, on the right side – from Scopus**. Hyphen is used when the journal is not in the top 5 journals in the relevant database (meaning that there are not enough relevant articles published in this journal to be among five most popular journals in respective topic in respective database). The most relevant journal (where the highest number of relevant articles are published) for each keyword search and each database is indicated in bold. Overall, three most popular journals taking into account all analysed keyword searches are Energies, IEEE Access and Sustainability.

When compared to Kushartadi *et al.* study on smart farming [31], the top journals for blockchain in agri-food sector are similar – the top ones for smart farming were identified as IEEE Access, Sensors, Sustainability. The difference is the top one journal for smart farming that does not show up on blockchain and agri-food – Computers and Electronics in Agriculture.

Core sources by Bradford's law (WoS data, zone 1 sources) for keyword searches are:

- 'Blockchain' and 'renewable energy' – Energies, IEEE Access, Sustainability, Applied Energy, Sensors, International Journal of Electrical Power & Energy Systems, Energy;
- 'Blockchain' and 'electric vehicle*' – IEEE Access, IEEE Transactions on Vehicular Technology, Energies, IEEE Transactions on Intelligent Transportation Systems, Sustainability, IEEE Internet of Things Journal;
- 'Blockchain' and 'agri-food' – Sustainability, IEEE Access, Journal of Cleaner Production, Sensors, Foods, British Food Journal, Applied Sciences etc.

3.6. Most Global Cited Documents

The most global cited documents from keyword searches with more than 35 articles are compiled in Annex 4 (supplementary file to this article) to provide a comprehensive source list on studied topics. It can be assessed that the Mengelkamp *et al.* publication on Brooklyn Microgrid [27] is definitely the most popular among publications about blockchain and renewable energy. Kang *et al.* research on peer-to-peer electricity trading using blockchain technology for plug-in hybrid electric vehicles is the most cited article on blockchain and electric vehicles [29]. Authors of this article propose a model for electricity trading among plug-in hybrid electric vehicles using smart grids, demand response and electric vehicles discharging to balance the demand. Su *et al.* publication on electric vehicles charging scheme using blockchain technology [30] must be mentioned regarding its first position for articles on topic 'blockchain technology', 'electric vehicles' and 'charging' and the fact that it is also in the list of most cited articles in topic 'blockchain technology' and 'renewable energy' and also in topic 'blockchain technology' and 'electric vehicles'.

The most cited articles on blockchain and agri-food sector (also including supply chains) are Kouhizadeh *et al.* and Dutta *et al.* [32], [33]. The first publication analyses technological, organization and environmental barriers for blockchain use in supply chains using industry and academic expertise, followed by use of Decision-Making Trial and Evaluation Laboratory (DEMATEL) tool. The second article also focuses on challenges in blockchain application in supply chains but also examines various sectors such as agri-food that could be transformed using blockchain technology.

3.7. Lotka's Law

To analyse the productivity of authors in the studied keyword searches Lotka's law on proportion of total authors versus documents written was used. As can be seen from Figure 7 around 85 % of authors have written one document in the particular keyword search. One tenth of the authors has participated in two articles on particular topic. The highest number of articles for one author is 11 for keyword search 'blockchain technology' and 'renewable energy', 10 for one author for keyword search 'blockchain technology' and 'electric vehicles', 16 for one author for keyword search 'blockchain technology' and 'agri-food'. These results suggest that all the topics are relatively new and (or) challenging because vast majority of authors (approximately 95 %) contributing to the research in these fields have only written one or two articles yet.

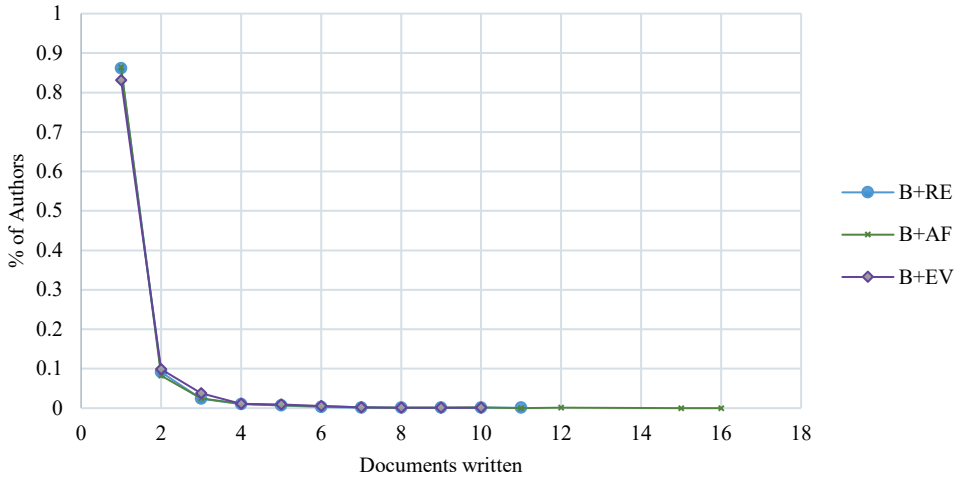

Fig. 7. Author productivity through Lotka's law (WoS data)

3.8. Corresponding Author's Countries

To find out which countries are doing research in blockchain and application fields studied in this paper, analysis of corresponding author's countries was performed. The top 10 countries for the keyword search 'blockchain' and 'renewable energy' in WoS database are (in descending order) China (130 articles from the total 396), India (24), Korea (16), United States of America, Germany, United Kingdom, Romania, Italy, Japan and Poland. In total 256 articles were written by corresponding authors from these countries. Scopus database includes also Norway and Pakistan. If the keyword 'storage' is added to the search, Saudi Arabia, Canada and Iran is added to the countries where more corresponding authors are working. The fact that China is the lead country in production of research on this topic was also found in Wang *et al.* bibliometric analysis on blockchain integration in energy sector [34].

Blockchain and electric vehicles are most studied in (descending order) China (120 articles in WoS from 298 total), India (35), United States of America (14), Canada, Saudi Arabia, Korea, Japan, Italy, Pakistan and United Kingdom. In total 230 articles were written by corresponding authors from these countries. If keyword 'charging' is added to the search, Australia, United Arab Emirates and Portugal joins the list of most popular countries from

corresponding authors perspective. If keyword ‘batteries’ is also added to the search, Egypt and Poland is represented in WoS data.

Blockchain and agri-food sector are most studied in (descending order) China (269 articles in WoS from 964 total), India (159), Italy (62), United States of America, United Kingdom, Spain, Australia, Korea, Saudi Arabia and Germany. Scopus database includes also Indonesia, Malaysia, Turkey and Greece. In total 686 articles were written by corresponding authors from these countries. The difference between this search and previous ones can be seen in the countries represented, for example, Spain is one of the lead countries from the corresponding authors perspective in this keyword search but is not represented in two other topics. Also, Italy is one of the top 3 countries in this search unlike the other searches. It must be highlighted that no changes between top countries happens if the search is more detailed (for example, the ‘supply chain’ keyword is added). It can be assumed that the majority of articles are written by corresponding authors working in these mentioned top countries, the most popular countries where corresponding authors are working are China and India.

3.9. Most Relevant Affiliations

To understand which are the affiliations where authors are working on analysed topics, the data about most relevant affiliations was gathered. This information on affiliations that are developing research in studied topics is relevant for the future collaborations between researchers. Blockchain and renewable energy is extensively studied in North China Electric Power University (China, 42 articles), King Saud University (Saudi Arabia, 15 articles) and Comsats University Islamabad (Pakistan, 14 articles) according to WoS data. For Scopus the first two affiliations are the same (with 80 and 25 articles respectively), the third is Xi’an Jiatong University (China) with 20 articles. It must be mentioned that if the keyword ‘storage’ is added, Huazhing University of Science and Technology (China) is the first most relevant affiliation (7 articles in WoS). Similar results on most relevant affiliations in this topic was found by Cui *et al.* [23]. For the topic on blockchain technology and electric vehicles, the most relevant affiliations according to WoS data are previously mentioned King Saud University (21 articles) and Comsats University Islamabad (17 articles), the third is Nirma University (India, 16 articles). Blockchain and agri-food sector is studied extensively in Beijing Technology and Business University (China, 56 articles in WoS), King Saud University (22 articles in WoS) and Nirma University (20 articles in WoS). If the keyword ‘supply chain’ is added, the Zhongkai University of Agriculture and Engineering (China, 18 articles in WoS) is amongst the most relevant affiliations.

3.10. Countries Collaboration Map

Fig. 8 and Fig. 9 show the existing collaboration between countries on studied topics. The more scientific production comes from a country, the darker it is shown on the map. As can be seen from Fig. 8 (showing the example of keyword search ‘blockchain technology’ and ‘renewable energy’) the main collaboration happens between China and United States of America, United Kingdom and Australia. Also, the collaboration between India and Saudi Arabia, Pakistan and Saudi Arabia must be taken into account. In this search China dominates as the country with the biggest scientific production (see also section 3.8.). Similar collaboration links were found by Cui *et al*. In study [25] it was concluded that China collaborates the most with United Kingdom, United States of America, Australia, Saudi Arabia, India, Canada, Italy and Pakistan. Similar results were obtained for blockchain and electric vehicles search.

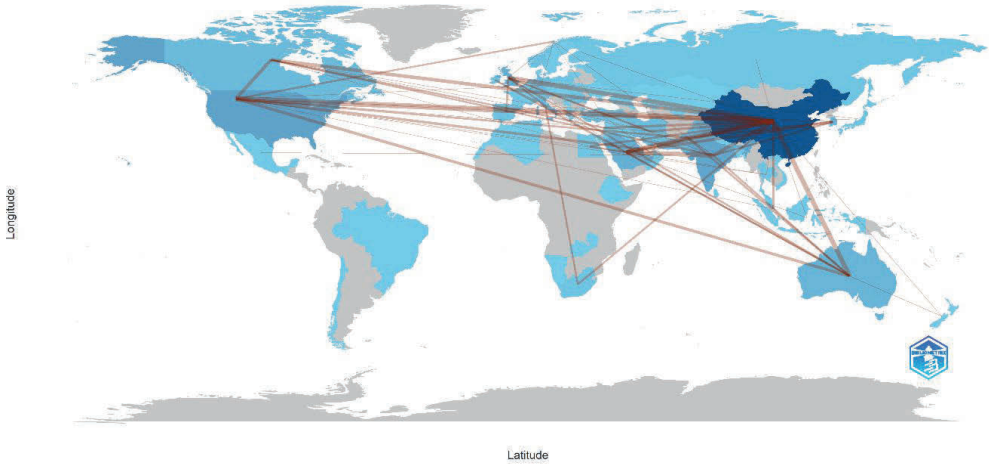

Fig. 8. Country collaboration map for B and RE, WoS data.

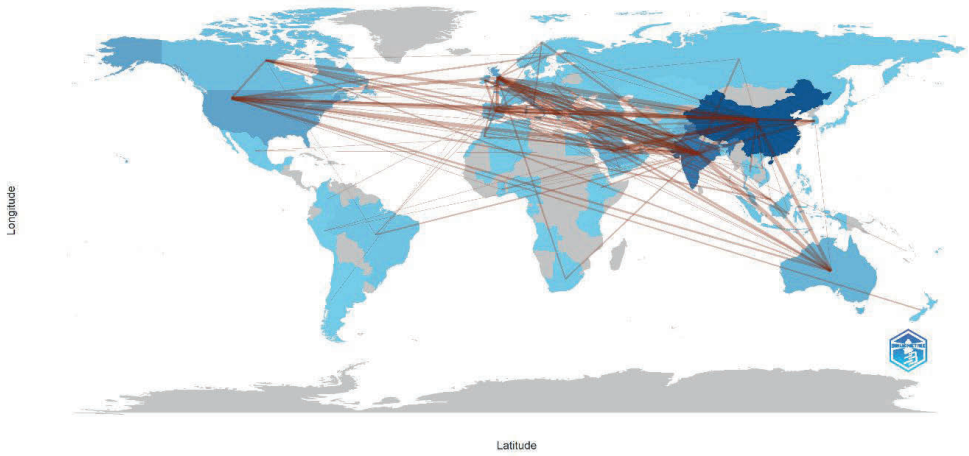

Fig. 9. Country collaboration map for B and AF, WoS data.

The example of keyword search 'blockchain technology' and 'agri-food' can be seen in Fig. 9. The collaboration between China, Australia, United Kingdom and United States of America is the most frequent in this topic too. In this case, India collaborates with Saudi Arabia, United Kingdom and United States of America more frequently than in the previous example. Also, the collaboration between Saudi Arabia and Pakistan is one of the most frequent. Collaboration between United Kingdom and France must be mentioned in this topic. In this search China and India dominates as the countries with the biggest scientific production (see also section 3.8).

3.11. Most Cited Countries

The data on most cited countries is compiled (see Annex 5) and analysed to provide the information on differences between countries scientific production described previously and the number of citations the produced articles holds. Annex 5 is structured similarly to

Annex 3 – only search results from keyword searches with results – more than 35 articles are shown, countries were included in the table only if they were in the top 5 for the specific topic. Data on total citation count from WoS is shown on the left side of the cell, on the right side – from Scopus. Hyphen is used when the country is not in the top 5 countries in the relevant database. Average article citation is shown in brackets for each database. The country with the biggest total citation count or highest average article citation is indicated in bold. As a result, it can be assumed that the most cited country in every case is China but the attention must be paid to the average article citations representing the choice of other authors to include this publication in their research. Singapore and Australia must be highlighted in the case of 'blockchain technology' and 'renewable energy' keyword search, Italy in both databases has gained the highest average article citations when keyword search is extended to include 'storage'. Blockchain and electric vehicles articles from Canada in both databases have the highest average article citations, but when the search is extended including 'charging' – United States of America and United Kingdom are among the top ones. Also United Kingdom dominates if the search is further extended to include 'batteries' – in the Scopus database one article is cited 163 times which is the highest citation count in all cases. United States dominates in blockchain and agri-food sector search (also including 'supply chains'). This data provides insights about the quality and novelty of empirical research among most cited countries and articles from those countries and should be considered when choosing previously mentioned future collaborations.

3.12. Trend Topics

To identify the trends connected to keywords used in articles and their frequency, an analysis on keywords plus for the three main keyword searches was performed and the results can be seen in Figs. 10–12.

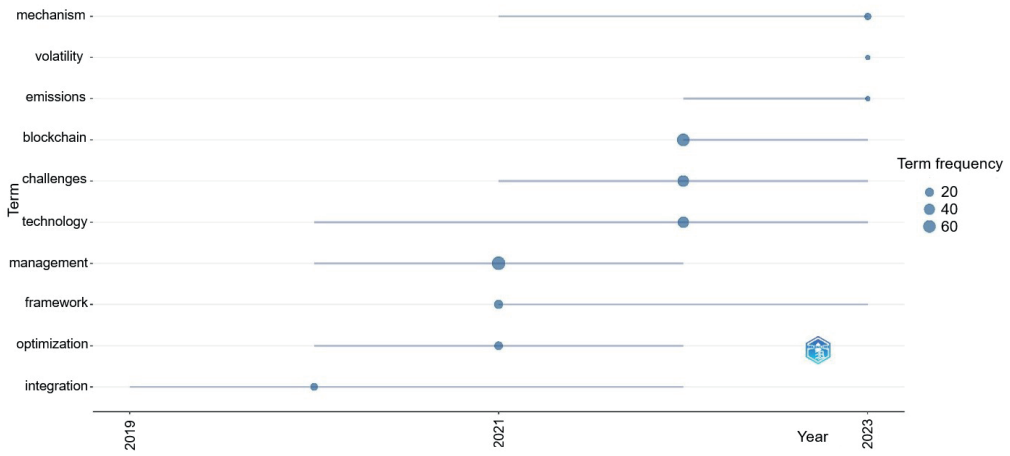

Fig. 10. Trend topics for 'blockchain' and 'renewable energy', Scopus data.

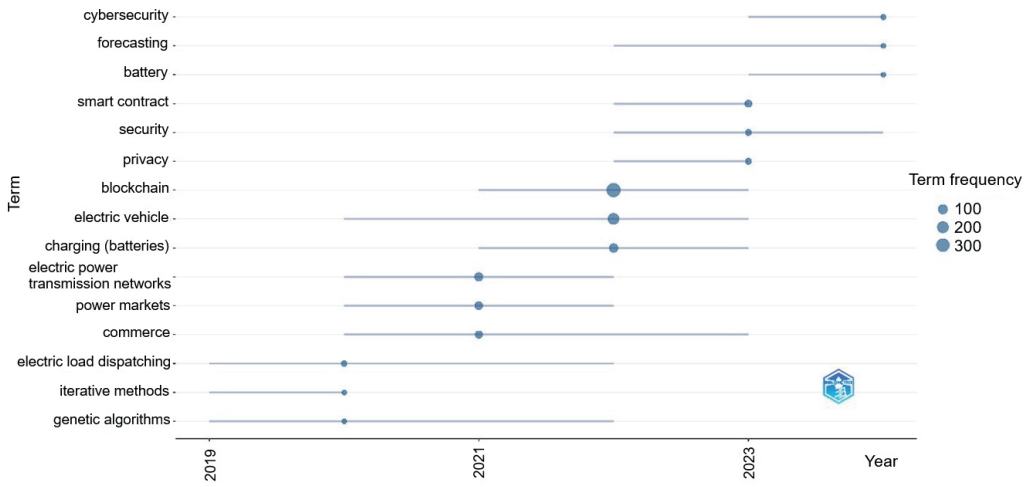

Fig. 11. Trend topics for ‘‘blockchain’ and ‘electric vehicle*’, Scopus data.

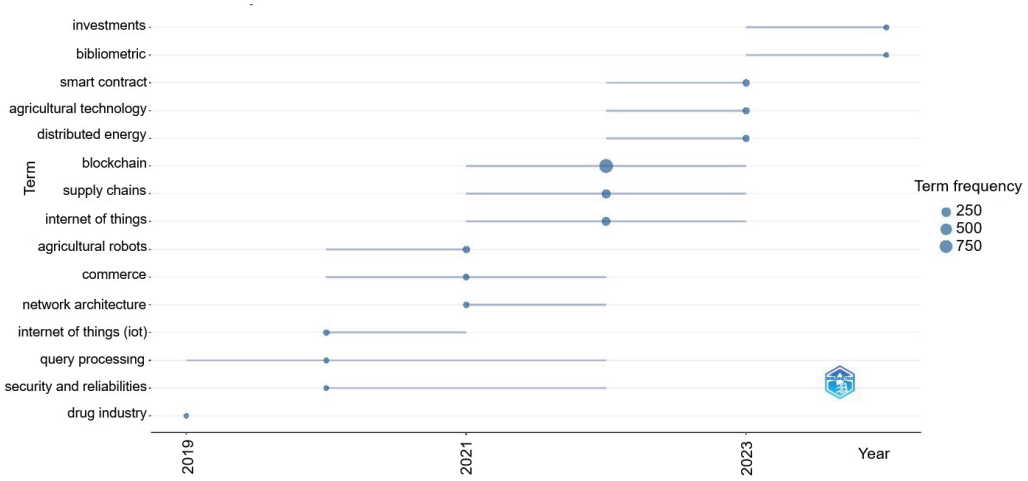

Fig. 12. Trend topics for ‘blockchain’ and ‘agri-food’, Scopus data.

As can be seen in Fig. 10 besides integration and optimization, management and challenges were trendy topics in 2021–2022, at this point topics are evolving to emissions and volatility in the articles from this keyword search. In the case of blockchain and electric vehicles (Fig. 11) similar keywords to blockchain and renewable energy dominated in 2021–2022, at this time the topics include batteries, forecasting and cybersecurity. Supply chains and Internet of Things was the trendy topics in 2022 for blockchain and agri-food sector (Fig. 12). In 2023 and 2024 researchers are focusing on investments, smart contracts and agricultural technologies.

3.13. Thematic Evolution

Scopus data was used for thematic evolution analysis which describes keyword (keywords plus were used) evolution through years. For the blockchain and renewable energy topic (see

Fig. 1 in Annex 6 – supplementary file to this article) such keywords as 'cost benefit analysis' and 'energy trading' evolved into 'digital storage', 'commerce' and further into 'energy policy', 'carbon' and currently into 'smart power grids', 'economic development' and 'consensus algorithms' indicating at this time topical study directions.

In the development of topic on blockchain and electric vehicles (see Fig. 2 in Annex 6) such early used keywords as 'charging', 'electric power distribution', 'decentralization' and 'peer-to-peer' must be mentioned. At this time the keywords have evolved into 'battery management systems', 'game theory', 'secondary batteries', 'privacy by design', 'stochastic systems' etc. showing that the research is developing in this topic to include both practical aspects (for example, rechargeable batteries and data protection inclusion in technological design) and theoretical, academic aspects (for example, mathematical models from game theory, stochastic (random) systems etc.).

Blockchain and agri-food topic (see Fig. 3 in Annex 6) evolved from keywords like 'food safety', 'food industries', 'internet of things' through 'digitalization', 'automation' and 'network security' to 'consumer', 'sustainable development' and 'environmental economics'. All of the recent keywords suggests that human or consumer oriented digital solutions which provide network security and sustainable development using blockchain and Internet of Things are researched at this moment thus studies including these aspects are relevant at this time.

Overall, from thematic evolution analysis and previous section – trend topic analysis, it can be assumed that main risks for the implementation of blockchain applications in these sectors could be associated with cybersecurity, integration, costs and investments needed to implement blockchain solutions, but, on the other hand, opportunities – firstly, practical aspects like automation, increased safety (for example, in food sector), privacy by design and ability to forecast, secondly, more wide aspects related to sustainability and energy systems – development of power markets, reduction of emissions throughout supply chains.

3.14. Co-Occurrence Network

Scopus data from keywords plus shows keyword co-occurrence network for 'blockchain technology' and 'renewable energy' search in Fig. 13. It shows how energy systems' related keywords merge with blockchain, management and digital network systems.

Blockchain and electric vehicles co-occurrence network consists of two main clusters (see Fig. 14) accentuating privacy topics, charging, digital and energy storage questions.

Keyword search for blockchain in agri-food forms three keyword co-occurrence clusters (see Fig. 15) where main cluster represents technological aspects – smart solutions, IoT, digital and network related keywords while the second cluster represents agricultural supply chains, food traceability, food security and sustainability. Similar keywords (like 'IoT', 'big data', also 'blockchain', 'machine learning' etc.) were dominating in Morella *et al*. study from Spain on 4.0 technologies implementation in agri-food supply chains [35]. Transparency and traceability also were some of the main research clusters from Sahoo *et al.* study on blockchain use in supply chains [36] which matches keywords found in this research.

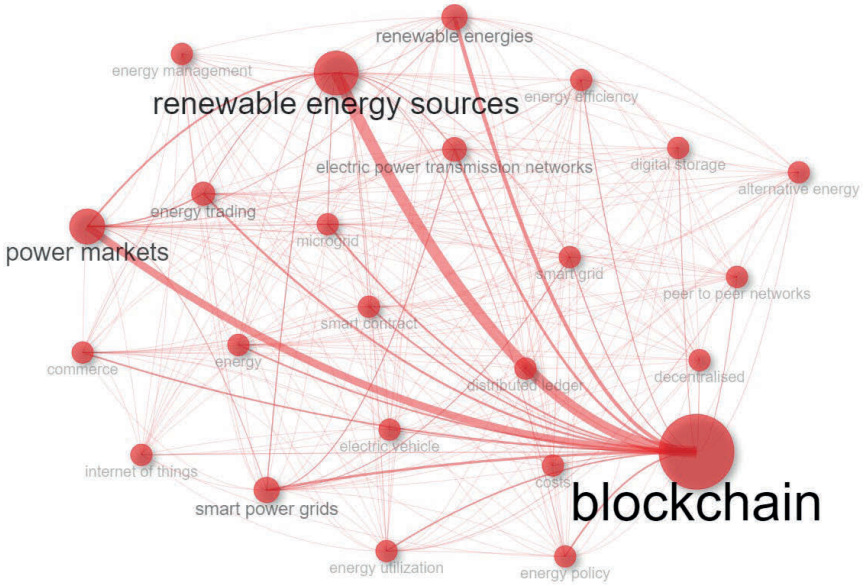

Fig. 13. Co-occurrence network for ‘blockchain’ and ‘renewable energy’, Scopus data.

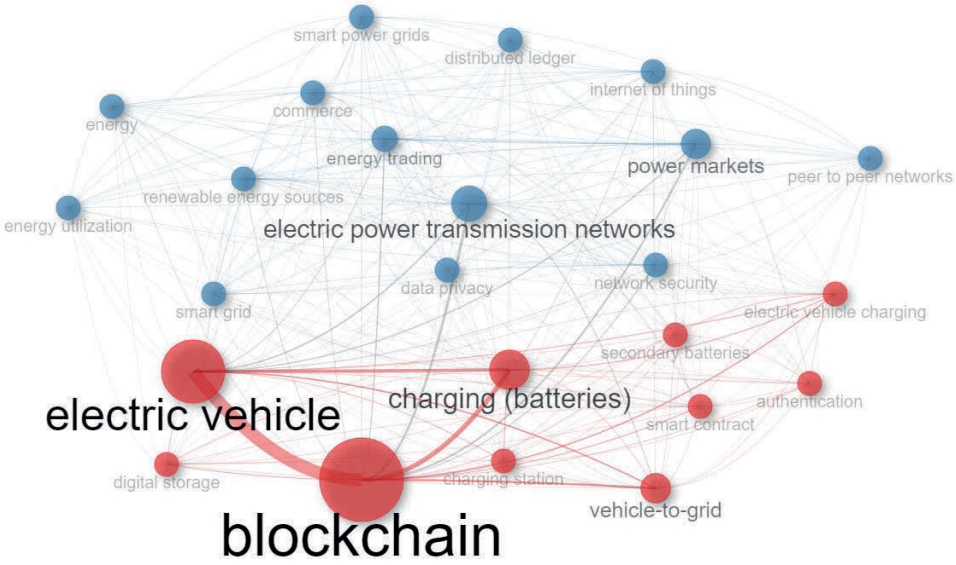

Fig. 14. Co-occurrence network for ‘blockchain’ and ‘electric vehicle*’, Scopus data.

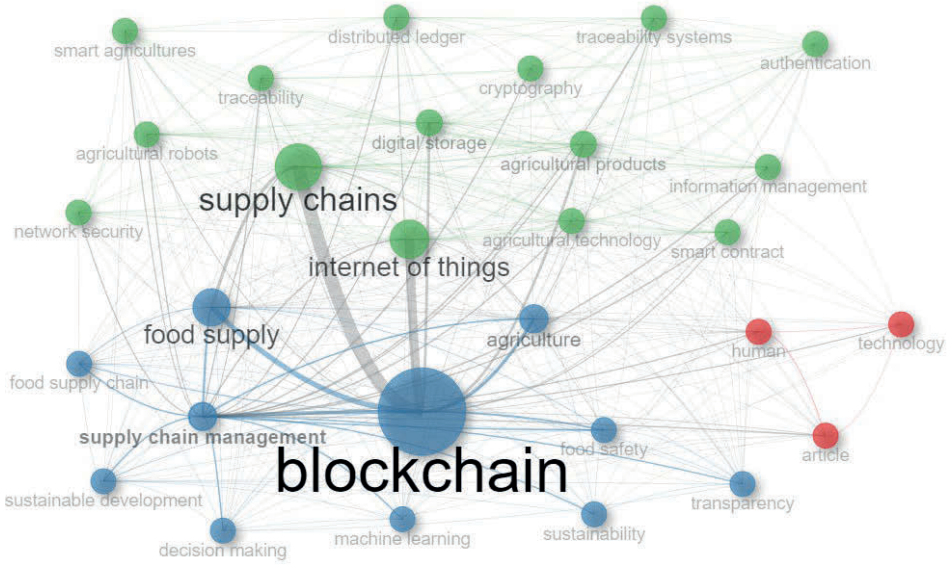

Fig. 15. Co-occurrence network for 'blockchain' and 'agri-food', Scopus data.

4. CONCLUSION

Overall, the results in this study does not contradict previously performed bibliometric analysis on similar topics, but it must be taken into account that this study for the first time (as far as the authors of this study are informed) combines topics covered in this level of detail. This study provides information on most popular scientific journals for analysed topics, also what are considered as good total and average citations in these topics, and most important – what are the topics that must be developed to fill the research gaps for blockchain adaption in renewable energy, electric vehicles and agri-food sector to foster the decarbonization, decentralization and digitalization processes. This article also contributes to existing small amount on bibliometric reviews specifically in blockchain and electric vehicles topic providing insights into this comparatively new topic.

Results also show that for the article to be cited and well-recognized unique, not widespread and fairly detailed topics should be studied and analysed. For example, the most cited articles are those that are early published in the given topic. Therefore, future research should be focused on those specific topics that can be described by keywords that are not yielding massive or any results at this point. Those would be, for example:

- blockchain in renewable energy with hydrogen (storage) systems;
- blockchain in electric vehicles' batteries supply chains considering raw materials and their circularity;
- blockchain in renewable energy (incl. storage) or electric vehicles considering life cycle and circularity details;
- blockchain in agri-food sector – life cycle approach, including circularity and recycling aspects.

The outcomes of this article will help scientific researchers to get comprehensive knowledge on current state of research in topics 'blockchain and renewable energy', 'blockchain and electric vehicles' and 'blockchain and agri-food sector', also the article

provides information on even more detailed sub-topics and in-depth analysis related to these topics. The information analysed should foster future research topics development and empirical studies in these fields. Based on this bibliometric analysis, the next steps for research in this field could be, for example, case studies and modelling of blockchain applications in analysed sectors, especially including life cycle and circularity aspects since the results of this study shows that these topics are not studied extensively yet.

Annex: https://zenodo.org/records/15526668

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