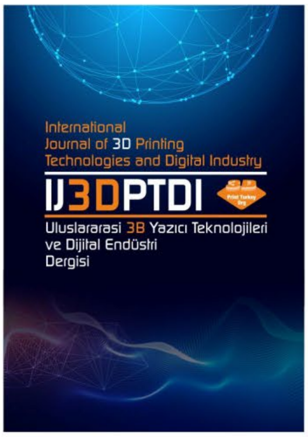


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# BIBLIOMETRIC OF BLOCKCHAIN PUBLICATIONS IN SCIENCE CITATION INDEX EXPANDED FROM 1991 TO 2022

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# BIBLIOMETRIC OF BLOCKCHAIN PUBLICATIONS IN SCIENCE CITATION INDEX EXPANDED FROM 1991 TO 2022

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## ABSTRACT

The aim of the paper is to perform a bibliometric study on blockchain which is an emerging technology presenting several advantages reinforcing security, privacy and immutability on a Peer-To-Peer network, inhibiting a central authority like a server. The studied articles are collected from the Clarivate Analytics Web of Science Core Collection database (data updated on 29 June 2023). A total of 11,190 blockchain documents were searched out in the SCI-EXPANDED from 1991 to 2022. The articles are analysed using characteristics of document types. The most used type is articles and reviews, relevant review articles, average numbers of citations per publication by year. The most cited publications are those published in 1991. The most cited Web of Science categories are “information systems computer science” and “electrical and electronic engineering”. The top most productive journals are IEEE journals and the top productive countries are China, USA and India. The top productive institutions are Beijing University of Posts and Telecommunications, Chinese Academy of Sciences, Xidian University. The top ten most frequently cited blockchain articles and the twenty most frequently used author keywords are exhibited to deduce trends of research in blockchain field. The contribution to the literature is reinforced by the given summary about the blockchain technology since 1991 and its developments, its actual shape and its trends toward the future.

**Keywords:** Blockchain, Bibliometrics, Blockchain articles, Bibliometric indicators, Blockchain trends.

## 1. INTRODUCTION

Blockchain is a peer-to-peer model that can speed up processes resulting in robust tracking and reducing costs of transactions. It is essential for business professionals to understand the significance of the implications of this far-reaching technology on business activities [1]. The transactions could be financial via cryptocurrency or another content like information. Blockchain technology permits to distribute, encrypt, and secure the records of digital transactions [2]. The blockchain is used in micro-credential to assess the student’s knowledge, skill, especially in the pandemic era [3].

It is used in accountability to speak today about decentralized accountability and an immutable audit. The blockchain reinforces the medical traceability of patients and the perishability of pharmacy products and agri-food. It is very efficient in e-voting and its credibility.

The addition of blocks of transactions to the chain is done by the miners which are nodes of blockchain network in competition to create and validate the block using an algorithm of hashage called consensus protocol. There are several consensuses more or less energy consuming, due to the used hardware and algorithm.

A transaction is initiated when one agent sends a cryptocurrency or a digital certificates to another agent. The transaction is controlled by the nodes on the network using a consensus mechanism like “proof Of Work”, solving a complex mathematical problem to validate the new block representing the transaction (Figure 1).

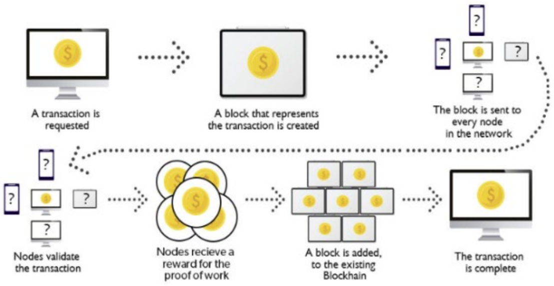


**Figure 1.** How a blockchain works? [75]

The blocks form a chronological chain, where each block in the chain contains a copy of the previous block's hash, ensuring that the data in the blocks cannot be altered. To organize the transactions between stakeholders, the smart contracts are used to self-executing contracts with the terms of the agreement are automated, limiting conflicts.

The blockchain is a decentralized and distributed system, making it more resistant to tampering and hacking, in addition to cryptography ensures that transactions are secure and the consensus mechanism ensures that the ledger is accurate and up-to-date.

The blockchain could enhance sustainability and contribute to the circular economy by optimizing consensus mechanisms.

Deep learning and blockchain technology have now become crucial, as it provides distinct and secure approaches to IoT (Internet of Things) network security [4].

The objective of this article is to perform a bibliometric study of blockchain in general not in a specific field, to help researchers to discover the actual state of the art and the future trends of blockchain.

The article is structured as follows: Section 2 explains methodology followed in the research to collect studied papers, their origin and some criteria applied to their selection. Section 3 presents results and discussion containing several aspects of the study ad comparisons. The article is finished by a conclusion.

## 2. METHODOLOGY

The data reported in this study were retrieved from the online version of the Science Citation Index EXPANDED (SCI-EXPANDED), the Clarivate Analytics Web of Science Core Collection database (data updated on 29 June 2023). In 2022, Journal Citation Reports (JCR) indexed 9,510 journals with citation references across 178 Web of Science categories in SCI-EXPANDED. The 2022 journal's impact factor (*IF*2022) was reported in the Journal Citation Reports (JCR) on 28 June 2023. According to the definition of the journal's impact factor, Chiu and Ho (2021) [5] recommended to search documents published in 2022 from SCI-EXPANDED after *IF*2022 was presented.

Quotation marks (" ") and Boolean operator "or" were used which ensured the appearance of at least one search keyword in the terms of TOPIC (title, abstract, author keywords, and Keywords Plus). The search was conducted using a targeted keyword, including "blockchain". To ensure the analysis results are as accurate as possible, uncommon terms such as "blockchains", "block chain", and "block chains" were also included. This approach was taken to ensure that the search is comprehensive and covers a wide range of documents related to the field of blockchain research.

A total of 11,190 blockchain documents were searched out in the SCI-EXPANDED from 1991 to 2022. The SCI-EXPANDED was mainly designed for researchers to find published literature, but not for bibliometric studies [6]. Thus, it is necessary to use an appropriate method when using the database for bibliometric studies. After checking, 10,840 documents (97% of 11,190 documents) from the SCI-EXPANDED were found from 1991 to 2022.

It was pointed that since Keywords Plus contains keywords that are selected based on the title of the articles mentioned in the references and footnotes [7], searching through it includes documents that not related directly to the topic [8], which may be suitable as readable sources but not for bibliometric analyzes [9].

The "front page" as a filter, including article title, abstract, and author keywords has been proposed by Ho's research group in 2011 [10,11]. It should be noted that using the "front page" compared to the 'Topic' directly in the database has a significant difference in the results [12]. By using "front page" as a filter, 10,248 documents (95% of the 10,840 documents) were defined as blockchain research publications.

The full record in SCI-EXPANDED and the number of citations in each year for each document were downloaded into Excel Microsoft 365, and additional coding was manually performed [13,14]. The functions in the Excel Microsoft 365, for example, Counta, Concatenate, Filter, Match, Vlookup, Proper, Rank, Replace, Freeze Panes, Sort, Sum, and Len were applied [14]. The journal's impact factors (IF2022) were taken from the Journal Citation Reports (JCR) published in 2022.

In the SCI-EXPANDED database, the corresponding author is labelled as reprint author, but in this study, the term corresponding author is used [15]. Single authors in articles with unspecified authorship were both the first as well as corresponding authors [16]. The single institution in articles with unspecified corresponding institutions was both the first as well as corresponding-author institutions [16]. Similarly, in a single-country article, the country is classified as the first as well as the corresponding-author country. In multi-corresponding author articles, all the corresponding authors, institutions, and countries were considered [14]. Articles with corresponding authors in SCI-EXPANDED, that had only address but not affiliation names were checked out and the addresses were changed to be affiliation names [14].

Affiliations in England, Scotland, North Ireland (Northern Ireland), and Wales were reclassified as being from the United Kingdom (UK) [17]. Affiliations in Turkiye were reclassified as being from Turkey. Affiliations from French Guiana were reclassified as being from France [18]. Affiliations in Faroe Islands were reclassified as being from Denmark [19].

## 3. CITATION INDICATORS

Publications were assessed using following citation indicators:
*C*year: the number of citations from Web of Science Core Collection in a year (e.g. *C*2022 describes citation count in 2022) [20].
*TC*year: the total number of citations from Web of Science Core Collection received since publication year till the end of the most recent year (2022 in this study, *TC*2022) [21].
*CPP*year: average number of citations per publication (*CPP*2022 = *TC*2022/*TP*), *TP*: total number of publications [22].

Countries and institutions indicators Six publication indicators were applied to evaluate publication performance of countries and institutions [23]:

*TP*: total number of articles
*IP*: number of single-country articles (*IP*C) or number of single-institution articles (*IP*I)
*CP*: number of internationally collaborative articles (*CP*C) or number of inter-institutionally collaborative articles (*CP*I)
*FP*: number of first-author articles
*RP*: number of corresponding-author articles
*SP*: number of single-author articles

Six citation indicators (*CPP*2022) related to the six publication indicators were also applied to evaluate the publication impact on countries and institutions [24].

## 4. RESULTS AND DISCUSSION

### 4.1. Characteristics of document types

In recent years, Ho's group identify the characteristics of document type based on their average number of citations per publication ($CPP_{year}$) and the average number of authors per publication (*APP*) as basic information of document type in a research topic [25]. Using $TC_{2021}$ and $CPP_{2021}$ is advantageous owing to their invariability and ensured repeatability as compared to the number of citations from the Web of Science Core Collection directly **[26].** A total of 10,248 documents published in the SCI-EXPANDED from 1991 to 2022 were found among 13 document types which are detailed in Table 1. This publication count includes 9,107 articles (89% of 10,248 documents) with an *APP* of 4.2 and CPP of 18, which considerably high and related to the novelty of blockchain technology. The document type of reviews with 756 documents had the greatest $CPP_{2022}$ value of 33 which was found to be 1.8 times of articles. Three of the top ten cited documents were reviews by [27, 28, 29] with a $TC_{2022}$ of 971, 788, and 767 respectively**.**

**Table 1.** Citations and authors according to the document type

| Document type | *TP* | % | *TP** | *AU* | *APP* | *TC*2022 | *CPP*2022 |
|---|---|---|---|---|---|---|---|
| Article | 9,107 | 89 | 9,107 | 38,612 | 4.2 | 161,756 | 18 |
| Review | 756 | 7.4 | 756 | 3,341 | 4.4 | 24,768 | 33 |
| Editorial material | 244 | 2.4 | 240 | 688 | 2.9 | 3,632 | 15 |
| Proceedings paper | 96 | 0.94 | 96 | 396 | 4.1 | 2,529 | 26 |
| Meeting abstract | 58 | 0.57 | 58 | 182 | 3.1 | 7 | 0.12 |
| Book chapter | 43 | 0.42 | 43 | 91 | 2.1 | 502 | 12 |
| Letter | 25 | 0.24 | 25 | 75 | 3.0 | 162 | 6.5 |
| Correction | 23 | 0.22 | 23 | 103 | 4.5 | 9 | 0.39 |
| News item | 19 | 0.19 | 16 | 17 | 1.1 | 588 | 31 |
| Retraction | 10 | 0.10 | 10 | 31 | 3.1 | 0 | 0 |
| Retracted publication | 8 | 0.078 | 8 | 33 | 4.1 | 137 | 17 |
| Book review | 6 | 0.059 | 6 | 6 | 1.0 | 1 | 0.17 |
| Data paper | 2 | 0.020 | 2 | 10 | 5.0 | 12 | 6.0 |

*TP*: number of publications; *TP**: number of publications with author information in the SCI-EXPANDED; *AU*: number of authors; *APP*: average number of authors per publication; $TC_{2022}$: the total number of citations from Web of Science Core Collection since publication year to the end of 2022; $CPP_{2022}$: average number of citations per publication ($TC_{2022}/TP$).

## 4.2. Relevant review articles

In [27], IoT (Internet of Things) are more vulnerable to attacks than other endpoint devices. Blockchain also provides a trustworthy decentralized management, governance, and tracking at every point in the supply chain and lifecycle of an IoT device (Figure 2).

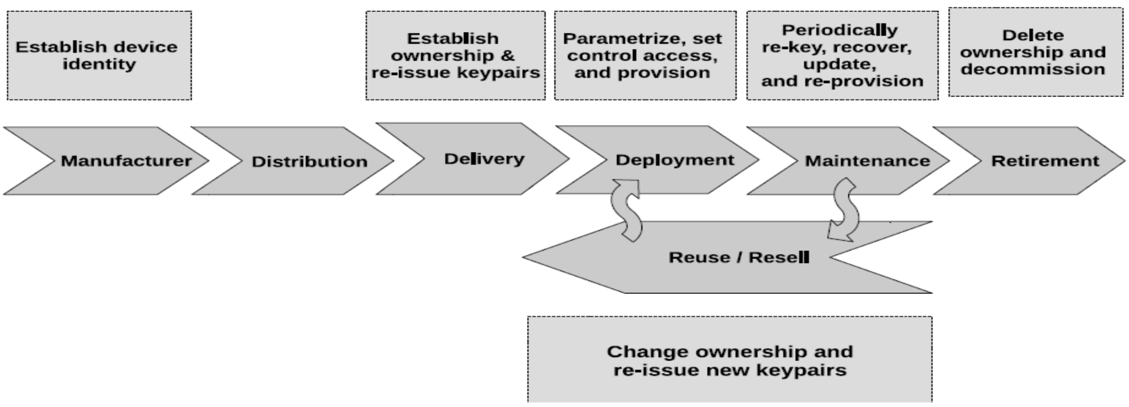


**Figure 2.** IoT device lifecycle security management [27]

According to [28], Figure 3 represents the challenges of blockchain as the lack of control in bitcoin address creation which is solved by certified users addresses from trusted authorities. The private key protection is solved by authentication by sharing private key between wallet and another device. Figure 1 gives a holistic analysis of the literature concerning challenges and their found solutions.

Authors of [29] show that most projects of blockchain in energy systems are in an early development phase, and research is still ongoing on key improvement areas that would allow desired scalability, decentralisation and technologies can be disruptive for energy companies and face a large variety of challenges to achieve market penetration, including legal, regulatory and competition barriers (Figure 4). Distributed ledger technologies and smart contracts can allow a generating unit to directly trade with a consumer or an energy retail supplier via autonomous trading agents cutting out the middle-man. The agent would search for the best deal in the marketplace that satisfies a consumer's forecast demand for a given period. The agreement would be safely recorded in the blockchain and automatically executed at the specified time of delivery. Payments would occur automatically at time of delivery as specified in agreed contract.

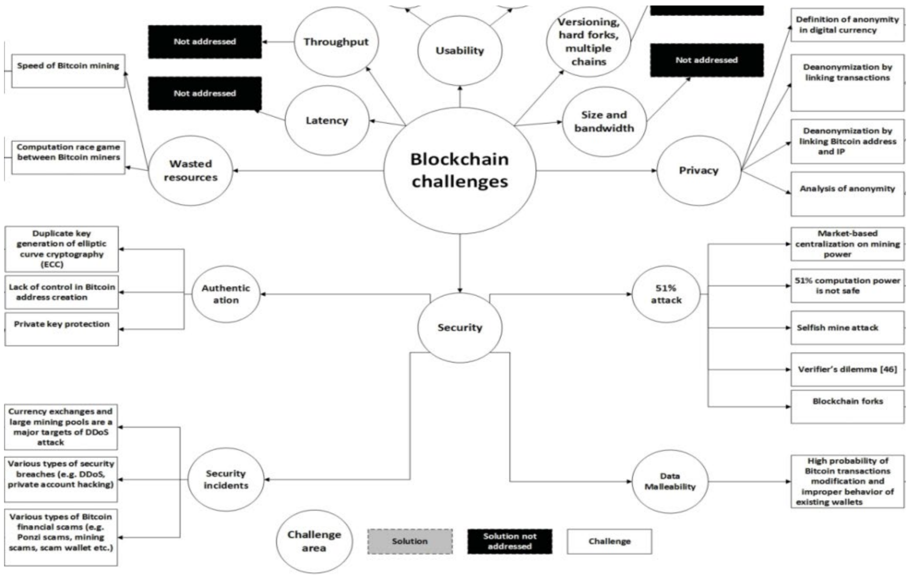


**Figure 3.** Summary of the identified challenges and solutions of Blockchain Adapted from [28]

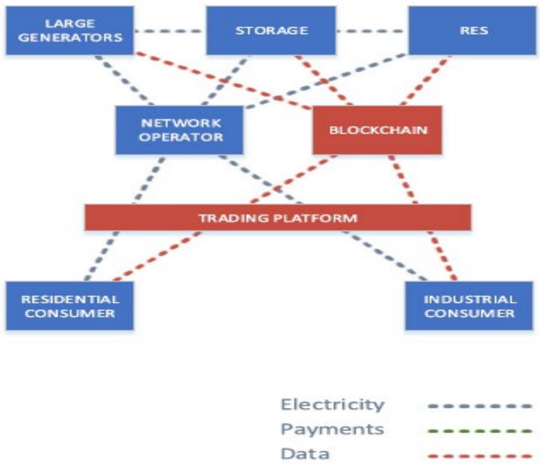


**Figure 4.** Transformation of market with blockchains according to PWC [29]

The supply chain can include multiple players such as factory, vendor, supplier, distributor, shipper, installer, owner, repairer, reinstaller, etc. As shown in Figure 2, keypairs can be changed and re-issued at multiple points during the lifecycle of an IoT device. Issuance of keypairs can be done initially by the manufacturer, then by the owner, periodically after deployment.

A total of 756 reviews were published in 227 journals mainly in the *IEEE Access* with an *IF*2022 of 3.9 (77 reviews; 10% of 756 reviews and the *Sustainability* with an *IF*2022 of 3.9 (59; 7.8%). It was point out that documents could be categorized in two document types in Web of Science Core Collection, for example, 96 proceedings papers, 41 book chapters, seven retracted publication, and one data paper were also classified in document type of articles. Therefore, cumulative percentages exceed 100% in Table 1 [30].

Contributions of various document types are different. Generally, articles contain introduction, methods, results, discussion, and conclusion, were chosen for further analyses [24].

A total of 9,107 articles were presented in four different languages. The most used language was English with 9,095 articles (99.9% of 9,107 articles) followed distantly by Chinese (7 articles), Japanese (3), and German (2).

**4.3. Characteristics of publication outputs**

Ho (2013) [22] proposed a correlation between annual number of articles (*TP*) and their average number of citations ($CPP_{year}$) by year to understand the development trends and impacts of publications in a research topic. Figure 4 demonstrates the distribution of the annual number of articles (*TP*) and their $CPP_{2022}$ by year. There were less than 20 annual articles from 1991 to 2015. An extremely increasing of trend was appeared since 2017 to reach 3,596 articles in 2022.

In Figure 5, we can see the scientific production increasing since 1991 (2 papers) to achieve 3596 in 2022. It is expected that it will increase in the future. The main average of citations per publication is 242, returns to the year 1991 and two articles about chemicals and polymers [31], [32]. The blockchain they speak about are written «block chain» and it means blocks of polymers and not the blockchain technology as defined in this work. All papers between 1991 and 2008 talk about the block chains of polymers. The first paper talking about blockchain technology is [33], where a new mutual authentication and privacy scheme for WLAN is proposed to address these security issues. The proposed scheme improves the security mechanisms of IEEE 802.11 and 802.1X by providing a mandatory mutual authentication mechanism between mobile station and access point (AP) based on public key infrastructure (PKI), offering data integrity check and improving data confidentiality with symmetric cipher block chain (CBC) encryption. The effective scientific production in blockchain technology began in 2016 and it is the most cited year with high average of citations (190) after 1991. After that the citations are decreasing until 2022.

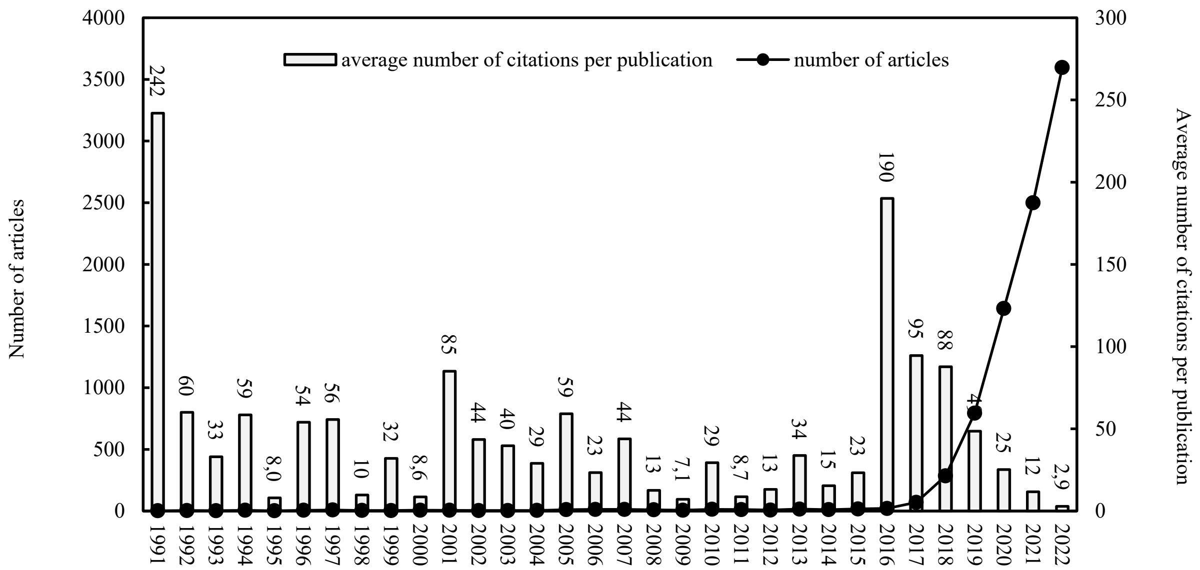


**Figure 5.** Number of blockchain articles and average number of citations per publication by year.

The mean value of $TC_{2022}$ was 18 with 1,799 as the maximal value for an article by [34]. In 1991, two articles had the greatest $CPP_{2022}$ of 242 which can be attributed to the article "Ordered structure in mixtures of a block copolymer and homopolymers.
Solubilization of low-molecular-weight homopolymers" [35] by Tanaka, Hasegawa, and Hashimoto from the Kyoto University in Japan, with a $TC_{2022}$ of 402. In 2016 with 13 articles had second high $CPP_{2022}$ of 304. The most frequently cited article [34] and top five cited article [36] were published in 2016.

**4.4. Web of Science Category and Journal**

In 2022, Journal Citation Reports (JCR) indexed 9,510 journals with citation references across 178 Web of Science categories in SCI-EXPANDED. Identify the characteristics of the Web of Science category based on their average number of citations per publication ($CPP_{year}$) and the average number of authors per publication (*APP*) as basic information of the Web of Science category in a research topic were presented in 2021 [37, 24].

Total of 843 journals published articles related to blockchain in 125 Web of Science categories in SCI-EXPANDED. A total of 5,356 articles (59% of 9,107 articles) were published in the top three categories: information systems computer science (3,959 articles; 43% of 9,107 articles), electrical and electronic engineering (3,301; 36%), and telecommunications (3,128; 34%). It is comprehensible because the blockchain technology uses techniques related to all these categories.

**Table 2.** The top 10 most productive Web of Science categories.

| Web of Science category | No. Journals | *TP* (%) | *APP* | $CPP_{2022}$ |
|---|---|---|---|---|
| Information systems computer science | 242 | 3959 (43) | 4.3 | 17 |
| Electrical and electronic engineering | 275 | 3301 (36) | 4.5 | 18 |
| Telecommunications | 88 | 3128 (34) | 4.4 | 18 |
| Theory and methods computer science | 111 | 834 (9.2) | 4.2 | 17 |
| Software engineering computer science | 108 | 737 (8.1) | 4.1 | 16 |
| Hardware and architecture computer science | 54 | 720 (7.9) | 4.4 | 17 |
| Interdisciplinary applications computer science | 110 | 551 (6.1) | 4.2 | 27 |
| Industrial engineering | 50 | 436 (4.8) | 4.3 | 41 |
| Applied physics | 159 | 424 (4.7) | 4.4 | 8 |
| Environmental sciences | 274 | 401 (4.4) | 3.9 | 14 |

*TP*: total number of articles; %: percentage in all articles; *APP*: average number of authors per paper; $CPP_{2022}$ average number of citations per paper ($TC_{2022}/TP$).

Comparing the top ten categories in Table 2, articles published in the category of industrial engineering had the greatest $CPP_{2022}$ of 41. Articles published in category of electrical and electronic engineering had the highest *APP* of 4.5. Recently, Ho proposed the characteristics of the journals based on their average number of citations per publication ($CPP_{year}$) and the average number of authors per publication (*APP*) as basic information of the journals in a research topic [38].

Table 3 shows the top 10 most productive journals with journal's impact factors, $CPP_{2022}$, and *APP*. The *IEEE Access* ($IF_{2022}$ = 3.9) published the most 952 articles which represent 4.3% of 9,107 articles. The *Security and Communication Networks* ($IF_{2021}$ = 1,968) and the *Wireless Communications & Mobile Computing* ($IF_{2021}$ = 2.146) were not classified in JCR in 2022. Comparing the top 10 productive journals in Table 3, articles published in the *IEEE Transactions on Industrial Informatics* ($IF_{2022}$ = 5.0) had the greatest $CPP_{2022}$ of 45 while articles in the *Wireless Communications & Mobile Computing* had only 3.2. The *APP* ranged from 5.1 in the *IEEE Internet of Things Journal* to 3.8 in the *Sustainability*. The journal with the greatest $IF_{2022}$ of 100.3 was the *Nature Reviews Immunology* ranked the top in 161 journals classified in the Web of Science category of immunology with one article followed by the *Nature* ($IF_{2022}$ = 64.8) ranked the top in 73 journals classified in the category of multidisciplinary sciences with two articles, and the *Nature Energy* ($IF_{2022}$ = 56.7) ranked the top in 115 journals classified in the category of energy and fuels with one article. The journals *Sustainability and Nature energy* are present in the list of top ten most productive journals because of the problem of consumption of energy by the mining process of the blockchain and the effect on environment.

**Table 3.** The top 10 most productive journals.

| Journal | *TP* (%) | $IF_{2022}$ | *APP* | $CPP_{2022}$ |
|---|---|---|---|---|
| IEEE Access | 952 (10) | 3.9 | 4.3 | 22 |
| IEEE Internet of Things Journal | 367 (4.0 | 10.6 | 5.1 | 29 |
| Sensors | 331 (3.6) | 3.9 | 4.6 | 12 |
| Sustainability | 265 (2.9) | 3.9 | 3.8 | 11 |
| Security and Communication Networks | 229 (2.5) | *1.968 | 4.6 | 4.6 |
| Applied Sciences-Basel | 204 (2.2) | 2.7 | 4.3 | 6.9 |
| Electronics | 177 (1.9) | 2.9 | 4.2 | 8.2 |
| Wireless Communications & Mobile Computing | 172 (1.9) | *2.146 | 4.1 | 3.2 |
| IEEE Transactions on Industrial Informatics | 158 (1.7) | 12.3 | 5.0 | 45 |
| Future Generation Computer Systems-The International Journal of Escience | 136 (1.5) | 7.5 | 4.5 | 44 |

*TP*: total number of articles; %: percentage of articles; $IF_{2022}$: journal's impact factor in 2022; *: journal's impact factor in 2021 ($IF_{2021}$); *APP*: average number of authors per article; $CPP_{2022}$: average number of citations per paper ($TC_{2022}/TP$).

### 4.5. Publication performances: countries and institutions

There were 12 articles (0.13% of 9,107 articles) without affiliations in SCI-EXPANDED. A total of 9,095 articles were published by authors affiliated from 113 countries including 5,444 single-country articles (60% of 9,095 articles) published by authors from 79 countries with a $CPP_{2022}$ of 15 and 3,651 internationally collaborative articles (40%) published by authors from 110 countries with a $CPP_{2022}$ of 22. The results demonstrated that internationally collaborative raised citations in the research of blockchain. It is widely recognized that two authors: first and the corresponding authors are considered as the most contributed authors in a research article [39]. At the institutional level, the determined institution of the corresponding author might be a home base of the study or origin of the paper [20]. Six publication indicators [23] and the six related citation indicators ($CPP_{2022}$) [24] were applied to compare the top 20 productive countries (Table 4). China dominated in all the six publication indicators with a *TP* of 4,079 articles (45% of 9,095 articles), an $IP_C$ of 2,422 articles (44% of 5,444 single-country articles), a $CP_C$ of 1,657 articles (45% of 3,651 internationally collaborative articles), an *FP* of 3,739 articles (41% of 9,095 first-author articles), an *RP* of 3,632 articles (40% of 9,083 corresponding-author articles), and an *SP* of 165 articles (35% of 466 single-author articles).

**Table 4**. Top 10 productive countries.

| Country | *TP* | *TP* | | $IP_C$ | | $CP_C$ | | *FP* | | *RP* | | *SP* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ***R* (%)** | $CPP_{2022}$ | ***R* (%)** | $CPP_{2022}$ | ***R* (%)** | $CPP_{2022}$ | ***R* (%)** | $CPP_{2022}$ | ***R* (%)** | $CPP_{2022}$ | ***R* (%)** | $CPP_{2022}$ |
| China | 4,079 | 1 (45) | 17 | 1 (44) | 11 | 1 (45) | 26 | 1 (41) | 16 | 1 (40) | 15 | 1 (35) | 4.7 |
| USA | 1,352 | 2 (15) | 29 | 4 (6.5) | 36 | 2 (27) | 27 | 3 (5.9) | 32 | 4 (6.9) | 31 | 2 (13) | 21 |
| India | 1,000 | 3 (11) | 15 | 2 (7.4) | 7.8 | 3 (16) | 19 | 2 (9.0) | 12 | 2 (7.6) | 12 | 6 (3.6) | 12 |
| South Korea | 734 | 4 (8.0) | 16 | 3 (7.4) | 14 | 8 (9.1) | 19 | 4 (5.5) | 16 | 3 (7.0) | 16 | 3 (5.8) | 11 |
| UK | 681 | 5 (7.5) | 23 | 9 (2.1) | 24 | 4 (16) | 23 | 6 (2.5) | 26 | 5 (3.3) | 23 | 9 (2.6) | 7.2 |
| Australia | 575 | 6 (6.3) | 24 | 7 (2.3) | 21 | 6 (12) | 25 | 5 (2.5) | 27 | 6 (3.2) | 26 | 7 (3.4) | 14 |
| Saudi Arabia | 573 | 7 (6.3) | 15 | 14 (1.2) | 4.2 | 5 (14) | 16 | 13 (1.7) | 9.4 | 10 (2.4) | 12 | 4 (5.2) | 3.8 |
| Canada | 472 | 8 (5.2) | 26 | 11 (1.5) | 18 | 7 (11) | 28 | 11 (1.8) | 18 | 11 (2.2) | 26 | 16 (0.86) | 12 |
| Taiwan | 375 | 9 (4.1) | 19 | 10 (2.0) | 11 | 10 (7.3) | 22 | 12 (1.7) | 11 | 7 (2.7) | 15 | 10 (2.4) | 17 |
| Japan | 346 | 10 (3.8) | 23 | 5 (3.2) | 20 | 11 (4.7) | 27 | 9 (2.4) | 22 | 8 (2.6) | 20 | 5 (4.5) | 10 |

*TP*: number of total articles; *TP R* (%): total number of articles and the percentage of total articles; $IP_C$ *R* (%): rank and percentage of single-country articles in all single-country articles; $CP_C$ *R* (%): rank and percentage of internationally collaborative articles in all internationally collaborative articles; *FP R* (%): rank and the percentage of first-author articles in all first-author articles; *RP R* (%): rank and the percentage of corresponding-author articles in all corresponding-author articles; *SP R* (%): rank and the percentage of first-author articles in all first-author articles; $CPP_{2022}$: average number of citations per publication ($TC_{2022}$/*TP*); N/A: not available.

Development trends in the publication of the top seven productive countries in the last decade are presented in Figure 6. The China ranked at the top in the last 10 years with a sharply increased since 2018 to reach 1,723 articles in 2022. India and Saudi Arabia also had sharply increased in recent years to reach 531 articles (ranked 2nd) and 290 articles (ranked 4th) in 2022 respectively. However, China had lower citations with a *TP*-*CPP*2022 of 17, an IPC-*CPP*2022 of 11, an FP-*CPP*2022 of 16, an RP-*CPP*2022 of 15, and an SP-*CPP*2022 of 4.7. Similarly, India Saudi Arabia also had lower *CPP*2022 for the six types of publications.

The UK was always exceeding production of China and all countries, but in 2022, China had 1723 articles, almost half of its *TP*. According to (Scimago, 2023) [40] ranking, the most productive and cited countries in all domains are USA, China then the UK. We see that Saudi Arabia is another country in perpetual scientific revolution. The blockchain domain is more supported by these countries, and this is the trend of all novelties in the world.

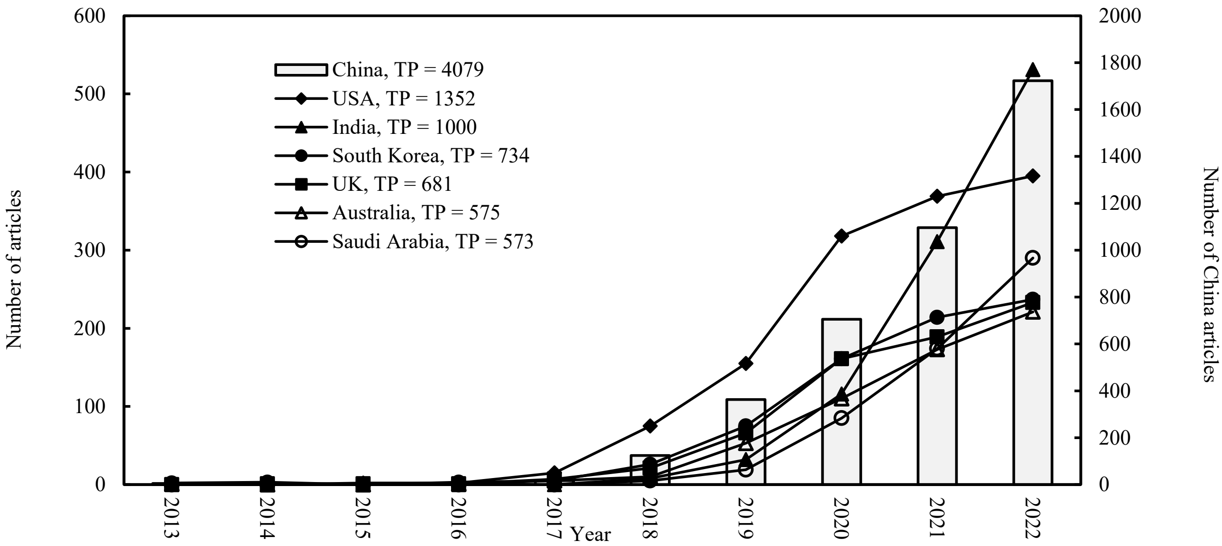

**Figure 6.** Development trends of the top seven productive countries.

Concerning institutions, 2,831 articles (31% of 9,095 articles) originated from single institutions with a $CPP_{2022}$ of 15 while 6,264 articles (69%) were inter-institutional collaborations with a $CPP_{2022}$ of 19.

The results show that international collaborations had higher citations than nationally collaborations. The top 10 productive institutions and their characteristics are presented in Table 5. Seven of the 10 institutions were in China and one in each of Saudi Arabia, Singapore, and Taiwan respectively. The Beijing University of Posts and Telecommunications (BUPT) in China dominated in five of the five publication indicators with a *TP* of 218 articles (2.4% of 9,095 articles), an $IP_I$ of 48 articles (1.7% of 2,831 single-institution articles), an *FP* of 160 articles (1.8% of 9,095 first-author articles), and an *RP* of 159 articles (1.8% of 9,083 corresponding-author articles).

BUPT is a comprehensive university with information and telecommunication technology as its main feature, engineering and science as its main focus and a combination of engineering, management, humanities and sciences as its main pursuit, which becomes an important base for fostering high-tech talents. BUPT has 11 schools, three research institutes. The three research institutes are Institute of Network Technology, Institute of Optical Communication and Photoelectron and Institute of Sensing Technology and Business [41]. They helped in promoting research. The university is chosen by 99% of Chinese students, it receives the most competent students, it explains the richness of its research.

The Chinese Academy of Sciences (CAS) in China ranked the top with a $CP_I$ of 198 articles (3.2% of 6,264 inter-institutionally collaborative articles). Compared to the top 10 productive institutions in Table 5, the Nanyang Technological University (NTU) in Singapore with a *TP* of 94 articles, a $CP_I$ of 91 articles, a *FP* of 35 articles, and an *RP* of 26 articles had the greatest of $TP$-$CPP_{2022}$ of 42, $CP_I$-$CPP_{2022}$ of 44, $FP$-$CPP_{2022}$ of 69, and $RP$-$CPP_{2022}$ of 53 respectively. The Hong Kong Polytechnic University (Poly U) with an $IP_I$ of eight articles had the greatest of $IP_I$-$CPP_{2022}$ of 49. Furthermore, the Asia University with an $IP_I$ of three articles (ranked 176$^{th}$) and a *FP* of nine articles (ranked 167$^{th}$) had much lower $IP_I$-$CPP_{2022}$ of 0 and $FP$-$CPP_{2022}$ of 1.9 respectively. Furthermore, Neeraj Kumar, affiliated with Thapar Institute of Engineering and Technology in India, utilized multiple affiliations for all articles, primarily with Thapar Institute of Engineering and Technology (TIET), Asia University in Taiwan, and King Abdul Aziz University in Saudi Arabia, to publish a substantial number of articles (56 out of 92) in Asia University. Kumar's role as an "academic mercenary," of Asia University by turning it into a gift institution.

**Table 5**. Top 10 productive institutions.

| Institution | *TP* | *TP* | | *IP*$_I$ | | *CP*$_I$ | | *FP* | | *RP* | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *R* (%) | *CPP*$_{2022}$ | *R* (%) | *CPP*$_{2022}$ | *R* (%) | *CPP*$_{2022}$ | *R* (%) | *CPP*$_{2022}$ | *R* (%) | *CPP*$_{2022}$ |
| BUPT, China | 218 | 1 (2.4) | 30 | 1 (1.7) | 13 | 2 (2.7) | 35 | 1 (1.8) | 29 | 1 (1.8) | 24 |
| CAS, China | 202 | 2 (2.2) | 22 | 117 (0.14) | 2.0 | 1 (3.2) | 23 | 4 (0.88) | 23 | 2 (1.2) | 20 |
| Xidian U, China | 167 | 3 (1.8) | 21 | 7 (0.6) | 20 | 4 (2.4) | 21 | 3 (1.1) | 19 | 3 (1.1) | 23 |
| KSU, Saudi Arabia | 162 | 4 (1.8) | 24 | 48 (0.28) | 10 | 3 (2.5) | 25 | 77 (0.18) | 22 | 7 (0.73) | 25 |
| UESTC, China | 153 | 5 (1.7) | 35 | 3 (0.85) | 14 | 5 (2.1) | 39 | 2 (1.1) | 34 | 3 (1.1) | 27 |
| BIT, China | 113 | 6 (1.2) | 27 | 7 (0.6) | 8.8 | 7 (1.5) | 31 | 4 (0.88) | 33 | 5 (0.9) | 33 |
| Poly U, China | 107 | 7 (1.2) | 33 | 48 (0.28) | 49 | 6 (1.6) | 32 | 21 (0.42) | 53 | 27 (0.36) | 39 |
| WHU, China | 99 | 8 (1.1) | 18 | 31 (0.35) | 8.9 | 9 (1.4) | 19 | 7 (0.66) | 20 | 6 (0.74) | 17 |
| NTU, Singapore | 97 | 9 (1.1) | 42 | 69 (0.21) | 10 | 8 (1.5) | 44 | 26 (0.38) | 69 | 46 (0.29) | 53 |
| Asia U, Taiwan | 92 | 10 (1) | 21 | 176 (0.11) | 0 | 9 (1.4) | 22 | 167 (0.1) | 1.9 | 38 (0.32) | 17 |

*TP*: total number of articles; *TP R* (%): total number of articles and percentage of total articles; *IP*$_I$ *R* (%): rank and percentage of single-institute articles in all single-institute articles; *CP*$_I$ *R* (%): rank and percentage of inter-institutionally collaborative articles in all inter-institutionally collaborative articles; *FP R* (%): rank and percentage of first-author articles in all first-author articles; *RP R* (%): rank and percentage of corresponding-author articles in all corresponding-author articles; *CPP*$_{2022}$: average number of citations per publication (*TC*$_{2022}$/*TP*); N/A: not available.

**Institutions**

BUPT: Beijing University of Posts and Telecommunications, CAS: Chinese Academy of Sciences, Xidian U: Xidian University, KSU: King Saud University, UESTC: University of Electronic Science and Technology of China, BIT: Beijing Institute of Technology, Poly U: Hong Kong Polytechnic University, WHU: Wuhan University, NTU: Nanyang Technological University, Asia U: Asia University.

Currently, Thapar Institute of Engineering and Technology in India is ranked 127th in the world and 20th in engineering [42], in 2023, and has 6 centers of excellence.

Centre for Business Analytics and Excellence focuses on the development of analytical thinking with large, ambiguous and complex data from diversified sources.

Centre for Learning Resource Development is being established with the mission of enriching management education.

Centre for Indian Management Critically evaluating and concretizing the Indian management thought and practice; developing conceptual frameworks, models and tools, thus helping practitioners to operationalize it.
The Centre for Governance undertakes action-oriented research which would be implemented by AF in collaboration with State Governments.

The centre for Academic and Corporate Leadership aimed to augment a collaborative academia-business interface.

Centre for Strategy, Sustainability & Society is envisioned to emerge as a catalyst for encouraging business strategy driven sustainability initiatives.

King Abdulaziz university is implementing a precise plan to improve the number and quality of scientific papers and is also keen to increase the rate of publication and citation among faculty members to achieve its goal of being among the top 100 universities to achieve the Kingdom's vision 2030. It also has an infrastructure of Specialized scientific and research entities represented by specialized entities, including supporting deanships, specialized research centers and laboratories, and research excellence chairs. The University is also interested in protecting, recording, marketing, and transforming promising ideas and inventions into commercial or industrial products [43].

### 4.6. Citation histories of the ten most frequently cited articles

Total citations are updated from time to time on the Web of Science Core Collection. To improve bibliometric study, the total number of citations from the Web of Science Core Collection since publication year to the end of the most recent year of 2021 (*TC*$_{2022}$) was applied to improve the bias using data from the database directly [21]. A total of 6,561 articles (72% of 9,107 articles), 8,857 articles (98% of 9,052 articles with abstract in SCI-EXPANDED), and 6,747 articles (87% of 7,757 articles with author keywords in SCI-EXPANDED) contain search keywords in their title, abstract, and author keywords respectively. Seven, eight, and ten of the top ten most frequently cited articles contain search keywords in their title, abstract, and author keywords respectively.

Table 6 shows the top 10 most frequently cited articles with two citation indicators [20].
The USA published four of the top ten articles, followed by China (3 articles), Germany (2),

Norway (2) and one for each of Spain, Canada and United Arab Emirates respectively. Three institutions including the Guangdong University of Technology in China, the Simula Research Laboratory in Norway, and the University of Oslo in Norway had two of the ten most frequently cited articles. Two of the top 10 articles published in the *IEEE Transactions on Industrial Informatics* and *Future Generation Computer Systems-the International Journal of Escience*. Citations of a highly cited article is not always high [44]. It is recommended to understand citation history of a highly cited article. The citation histories of the top ten articles contain search keywords in their title or author keywords are shown in Figure 7. The fundamental pattern observed was a steady rise in citations over a period of approximately three years, followed by a subsequent decline. Article entitled "Blockchains and smart contracts for the Internet of Things" [34] had the greatest impactful in blockchain research. However, a letter published article entitled "Blockchain technology and its relationships to sustainable supply chain management" [45] was the most impactful in the most recent year of 2022 with a $C_{2022}$ of 379.

All of the top ten most cited articles has three phases of citations; a weak beginning of citations, crucial phase of citations and then a weak end of citations (Figure 7). The shape of the citation history curves is similar for almost of the articles.

**Table 6.** Top 10 most frequently cited blockchain articles

| Rank ($TC_{2022}$) | Rank ($C_{2022}$) | Title | Country | Reference |
|---|---|---|---|---|
| 1 (1,799) | 3 (284) | Blockchains and smart contracts for the Internet of Things | USA | Christidis and Devetsikiotis (2016) [34] |
| 2 (1,185) | 2 (331) | Industry 4.0: State of the art and future trends | USA | Xu et al. (2018) [46] |
| 3 (1,139) | 4 (281) | Blockchain challenges and opportunities: A survey | China | Zheng et al. (2018) [47] |
| 4 (959) | 1 (379) | Blockchain technology and its relationships to sustainable supply chain management | USA | Saberi et al. (2019) [45] |
| 5 (734) | 31 (110) | Bitcoin and beyond: A technical survey on decentralized digital currencies | Germany | Tschorsch and Scheuermann (2016) [36] |
| 6 (713) | 8 (168) | Designing microgrid energy markets. A case study: The Brooklyn Microgrid | Germany, USA | Mengelkamp et al. (2018) [48] |
| 7 (652) | 9 (166) | On blockchain and its integration with IoT. Challenges and opportunities | Spain | Reyna et al. (2018) [49] |
| 8 (611) | 20 (127) | Security and privacy in decentralized energy trading through multi-signatures, blockchain and anonymous messaging streams | U Arab Emirates | Aitzhan and Svetinovic (2018) [50] |
| 9 (604) | 13 (149) | Consortium blockchain for secure energy trading in industrial Internet of Things | China, Norway | Li et al. (2018) [51] |
| 10 (590) | 19 (128) | Enabling localized peer-to-peer electricity trading among plug-in hybrid electric vehicles using consortium blockchains | China, Norway, Canada | Kang et al. (2017) [52] |

$TC_{2022}$: the total number of citations from Web of Science Core Collection since publication year to the end of 2022; $C_{2022}$: number of citations of an article in 2022 only.

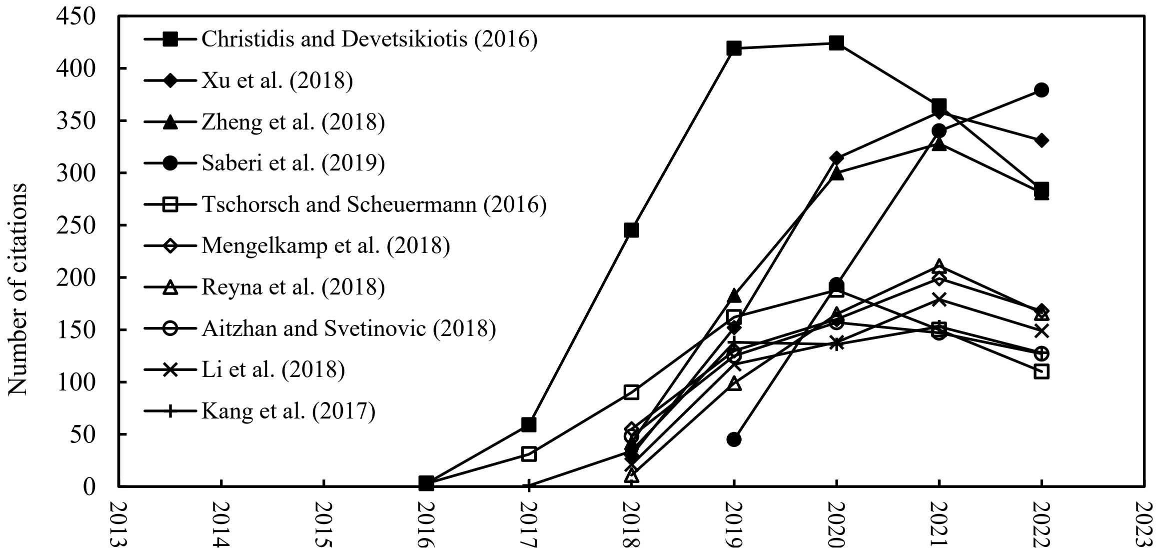

**Figure 7.** The citation histories of the top ten most frequently cited articles.

**Table 7.** Findings and contributions of Top 10 most frequently cited blockchain articles

| Title | Findings and contributions |
|---|---|
| Blockchains and smart contracts for the Internet of Things [34] | blockchain-IoT combination facilitates the sharing of services and resources leading to the creation of a marketplace of services between devices and allows to automate in a cryptographically veriable manner several existing, time-consuming workflows. |
| Industry 4.0: State of the art and future trends [46] | Blockchain is an industry 4.0 technology, World Economic Forum predicts that by 2027, 10% of global GDP will be stored on blockchain technology. Some companies have started integrating blockchain concept into manufacturing practices. |
| Blockchain challenges and opportunities: A survey [47] | The article contains a comparison between consensuses which represent a vital part concerning the energy consumption and its minimization. It compares PoW, PoS, PBFT, DPOS, Ripple and Tendermint. They found that Pos and DPoS are the less cosuming energy. |
| Blockchain technology and its relationships to sustainable supply chain management [45] | Four blockchain technology adoption barriers categories are introduced: interorganisational barriers (lack of customers' awareness, lack of collaboration, challenge of sustainability practices and cultural differences), intraorganisational barriers (financial constraints, lack of managers' support), technical barriers (security challenge, blockchain not mature, immutability challenge) and external barriers (lack of governmental policy, market competition, lack of stakeholders involvement). |
| Bitcoin and beyond: A technical survey on decentralized digital currencies [36] | A comparison between bank model and bitcoin model: The bank Model is centralized, survives by interests of loans, value of money depends on rate exchange, and the tranfer is mediated and not free, long delay of transaction with high fees).The Bitcoin Model is decentralized, survives by mining operations, value of money depends on demand and supply, and the tranfer is direct and not reversible, short delay of transaction with low fees). |
| Designing microgrid energy markets. A case study: The Brooklyn Microgrid [48] | The article shows that private blockchains are suitable information systems that can facilitate localized energy markets. The BMG is the first project that actually facilitated a blockchain-based electricity transaction. The projects' findings need to be further investigated to evaluate the economic and socio-economic impact of microgrid energy markets on their participants and the entire energy supply system. |
| On blockchain and its integration with IoT. Challenges and opportunities [49] | Consensus can include IoT as part of the mining processes and distributing even more blockchains. Beyond the scalability and storage capacity which affect both technologies, research should ensure the security and privacy of critical technologies that the IoT and blockchain can become. One of the main concerns about blockchain, and especially cryptocurrencies, resides in its volatility which has also been exploited by people to take unfair advantage of this situation. The integration of the IoT and blockchain will increase the use of blockchain, to establish cryptocurrencies on the same level as current money. |
| Security and privacy in decentralized energy trading through multi-signatures, blockchain and anonymous messaging streams [50] | Authors implemented a proof-of-concept for decentralized energy trading system using blockchain technology, multi-signatures, and anonymous encrypted messaging streams, enabling peers to anonymously negotiate energy prices and securely perform trading transactions. On the case studies, they found that the appropriate combination of blockchain technology, multi-signatures and anonymous encrypted message propagation streams presents a feasible and reliable direction towards decentralized energy trading with higher privacy and security compared to the traditional centralized trading solutions. |
| Consortium blockchain for secure energy trading in industrial Internet of Things [51] | In this paper, a unified energy blockchain based on consortium blockchain for secure energy trading in various typical scenarios of IIoT (Industrial IOT), such as microgrids, energy harvesting networks, and vehicle-to-grids. Authors designed a credit-based payment scheme to overcome the transaction limitation caused by transaction confirmation delays, which supports fast and frequent energy trading by credit-based payment among energy nodes. They propose an optimal pricing strategy using Stackelberg game for energy-coin loans to maximize economic benefits of credit banks. |
| Enabling localized peer-to-peer electricity trading among plug-in hybrid electric vehicles using consortium blockchains [52] | A localized P2P Electricity Trading system with Consortium blockchaiN (PETCON) method is proposed to illustrate detailed operations of localized P2P electricity trading. Moreover, the electricity pricing and the amount of traded electricity are solved by an iterative double auction mechanism to maximize social welfare in this electricity trading. Security analysis shows that the proposed PETCON improves transaction security and privacy protection. Numerical results based on a real map of Texas indicate that the double auction mechanism can achieve social welfare maximization while protecting privacy of the PHEVs. |

Table 7 summarizes the content of the top ten most cited articles. Most of them are reviews of the different aspects of blockchain.

### 4.7. Research foci

The study conducted by [53] utilized the distribution of words in article titles, abstracts, author keywords, and *Keywords Plus* as a word bank to identify the research's main focuses and their development trends. However, when it comes to new research topics or fields, analysing different periods may not be appropriate. The articles were arranged in ascending order based on their publication years and were subsequently divided into three distinct "periods". Each period contains one-third of the total articles. In the first period, spanning from 1991 to 2020, amounting to 3,011 articles (33% of the overall 9,107 articles), were accounted for. This initial period represented a smaller proportion of articles each year, suggesting the emergence of a new research topic or field. It took 20 years to publish

**Table 8.** The 20 most frequently used author keywords

| Author keywords | *TP* | 1991-2022 Rank (%) | 1991-2020 Rank (%) | 2021 Rank (%) | 2022 Rank (%) |
|---|---|---|---|---|---|
| Blockchain | 5930 | 1 (76) | 1 (76) | 1 (86) | 1 (70) |
| Security | 1,076 | 1 (14) | 1 (9.1) | 1 (16) | 1 (16) |
| Internet of things | 824 | 2 (11) | 1 (9.1) | 2 (11) | 2 (12) |
| Smart contract | 777 | 3 (10) | 3 (8.8) | 3 (10) | 3 (11) |
| Smart contracts | 745 | 4 (10) | 4 (8.2) | 4 (10) | 4 (11) |
| Privacy | 617 | 5 (8.0) | 6 (6.2) | 5 (9.3) | 5 (8.5) |
| Bitcoin | 425 | 6 (5.5) | 5 (6.7) | 7 (5.2) | 8 (4.7) |
| Cloud computing | 352 | 7 (4.5) | 8 (4.3) | 12 (4.6) | 8 (4.7) |
| IoT | 352 | 7 (4.5) | 7 (4.8) | 9 (4.9) | 11 (4.1) |
| Blockchain technology | 335 | 9 (4.3) | 11 (3.5) | 12 (4.6) | 7 (4.8) |
| Edge computing | 335 | 9 (4.3) | 10 (3.6) | 6 (5.8) | 12 (3.9) |
| Ethereum | 331 | 11 (4.3) | 9 (4.3) | 7 (5.2) | 14 (3.6) |
| Authentication | 329 | 12 (4.2) | 15 (2.9) | 9 (4.9) | 6 (4.9) |
| Peer-to-peer computing | 280 | 13 (3.6) | 14 (3.0) | 14 (4.1) | 13 (3.8) |
| Servers | 278 | 14 (3.6) | 23 (1.8) | 11 (4.9) | 10 (4.2) |
| Internet of Things (IoT) | 276 | 15 (3.6) | 12 (3.4) | 15 (3.8) | 15 (3.5) |
| Access control | 255 | 16 (3.3) | 16 (2.8) | 16 (3.8) | 16 (3.3) |
| Machine learning | 214 | 17 (2.8) | 18 (2.3) | 20 (3.1) | 17 (3.0) |
| Distributed ledger | 212 | 18 (2.7) | 19 (2.2) | 18 (3.2) | 18 (2.8) |
| Cryptography | 205 | 19 (2.6) | 17 (2.6) | 17 (3.4) | 29 (2.2) |
| Scalability | 191 | 20 (2.5) | 34 (1.5) | 19 (3.1) | 19 (2.8) |

*TP*: number of articles contain the keywords; %: percentage in each period.

one-third of the total articles. Moving on to the second period, which encompassed the year 2021, totalling 2,500 articles (27% of the 9,107 total articles). During this period, researchers displayed increased interest, leading to a higher volume of published studies. It took only on year to publish one-third of the total articles. Finally, period three covered 2022, with 3,596 articles (39% of the 9,107 total articles). Again, it only took one year to publish one-third of the total articles. The analysis involved examining the distribution of words in the article titles and abstracts, as well as author keywords, across these three article segments. The analysis of words in article titles and abstracts provides insights limited to individual words. In Table 8, the 20 most frequently used author keywords (excluding search terms) were highlighted.

The results of keyword analyses provide information about the main and possible research foci as each word cluster comprised several supporting words.

The frequensy of the keyword «blockchain» (5930) is added to the frequency of «blockchain technology» (335) to obtain 6265, and because they are synonyms and the most frequent; it is obvious by the nature of the bibliometrics research looking for blockchain articles.

The security is the second most frequent keyword (1,076) to understand that the appeal to the blockchain technology is for its encouraging security aspect. The keywords privacy (617), authentication (329), access control (255) and cryptography (205) belong to the security family. Figure 8 illustrates that the security of the blockchain should be insured at all the levels or layers. The third most frequent keyword is «Internet of Things» (824), added to the keyword IOT (352) and added to Internet of Things (IoT) (276) to obtain 1492 appearances of the keywords having the same meaning. The next trend of blockchain is the acceleration of integration of blockchain and IOT, because IOT are subject of attacks and the blockchain may reinforce their security.

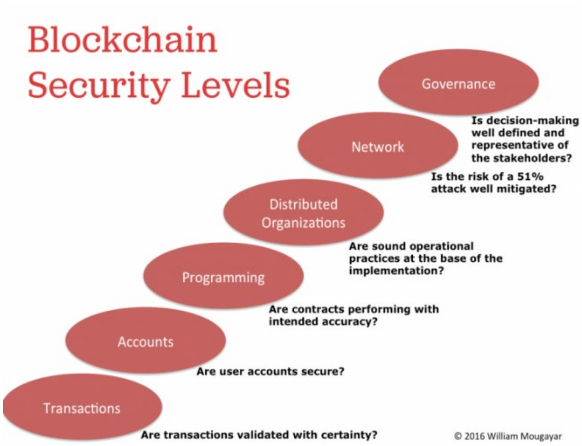


**Figure 8.** Blockchain security levels [54]

The fourth more used keyword is smart contract (777) added to smart contracts (745) to have 1522. The smart contract is an automated contract reflecting the real contract or the traditional contract. It works on blockchain without reminders or negotiations. All is done in advance when designing the blockchain. The fifth most used cryptocurrency or digital money is Bitcoin (425) and followed by Ethereum (331).

The first one appeared in 2008 and was announced by a group under the pseudonyme Satoshi Nakamoto (unknown until now) by publishing their white paper « Bitcoin: A Peer-to-Peer Electronic Cash System » [55]. In 2012, the bitcoin achieves 1 billion dollars. In 2013, [56] launched the Ethereum. While both the Bitcoin and Ethereum networks are powered by the principle of distributed ledgers and cryptography, the two differ technically in many ways. For example, transactions on the Ethereum network may contain executable code, while data affixed to Bitcoin network transactions is only used to record transaction information. Other differences include block time (an ETH transaction is confirmed in seconds, compared with minutes for BTC), and their consensus algorithms are different: Bitcoin uses SHA-256, while Ethereum uses LMDGhost [57]. The particularity is that each enterprise can create its own cryptocurrency convertible to other cryptocurrencies and traditional currencies. That is why, there are thousands of cryptocurrencies.

The sixth trend is the computing infrastructure supporting the blockchain represented by the keywords: cloud computing (352), edge computing (335) and peer-to-peer computing (280) to have in final (967) appearances.

The cloud computing is commonly described as the usage of computing resources provided as services over network [58].

(Zhou et al. 2017) [59] proposed a Cleanroom Security Service Protocol (CSSP), which is actually a bilateral agreement based on a consortium blockchain framework, shown in Figure 9. CSSP was mainly designed for the SaaS (Software as a Service) computing environment [60]. The usage of blockchain with cloud computing is to be more trustful.
Figure 10 shows the asked researches on Google about cloud computing since 2004. It is increasing these last years [61].

The increasing usage of the Internet of Things over the time has caused problems to the centralized resources on Cloud Computing like low throughput, high latency, bandwidth bottlenecks, data privacy, centralized vulnerabilities, and additional costs.

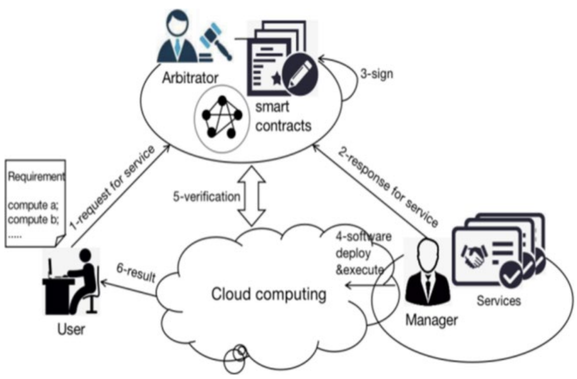


**Figure 9.** Main process in CSSP [60].

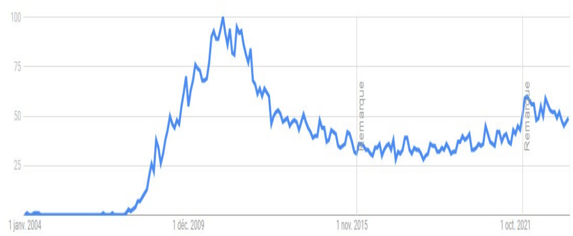


**Figure 10.** The trends of research on Google about Cloud computing [61].

To attenuate these problems, the Edge Computing is appeared, simply to delegate the hard computations to the peripherals and terminals to gain some decentralization [62]. Figure 11 illustrates the increasing trends of researches on Edge Computing over the time [61].

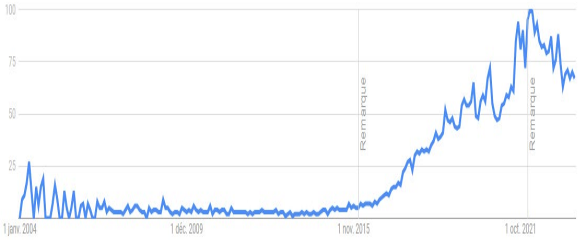


**Figure 11.** The trends of research on Google about Cloud computing [61].

The seventh trend is Peer-To-Peer (P2P) computing (280) added to distributed ledger (212) to have 492. P2P is a computing network without a central server, it is the more adequate to the decentralized architecture of blockchain technology. Figure 12 [63] is the architecture of the P2P network.

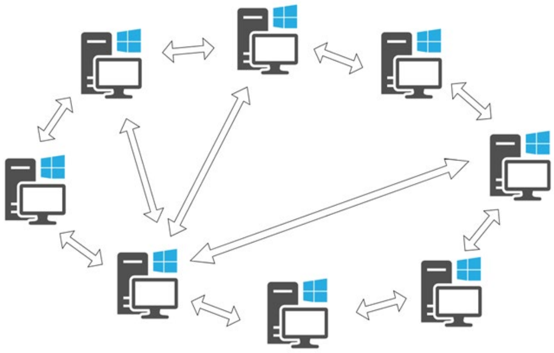

**Figure 12.** A simulation of a peer-to-peer network [63]

Figure 13 [61] illustrates the stabilisation of researches on Google over 12 years, there is probably an increasing use of it with the increasing of use of blockchain in the future.

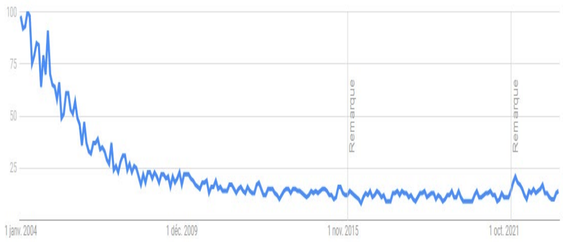


**Figure 13.** The trends of research on Google about P2P Network [61].

### 4.8. The studied Consensuses

A consensus algorithm is a compliance of each actor in the blockchain network in order to agree on the creation and sequence of each block, it is a tedious verification process ensuring that the blockchain transaction history is correct and tamperproof. All players or nodes of the network must agree to validate an entry in the blockchain register, this is called a consensus algorithm [64].

Table 9 shows the most 12 used consensuses in the studied articles expressed in author keywords. The first keyword is consensus equivalent to algorithm, protocol or mechanism with 480 appearance. It does not specify the used consensus.

We will describe the top 4 used consuses. The most specified used consensus is «Byzantine fault tolerance» (BFT) with a frequency of 111. BFT proposes series of fault-tolerant consensus algorithms that enable the system to reach consensus even in the presence of a certain number of malicious nodes of the blockchain network [65]. While Proof of Work (PoW) with 101 appearances, was the first used in consensus in blockchain, it requires the consent of all nodes in the network without exception for the addition of a block, which makes the process long (10 minutes), energy consuming and above all the most secure. PoW has been improved by several versions to mitigate its disadvantages.

The third consensus if Proof of Knowledge (PoK) (68), a better version of PoK is Zero-knowledge Proof (ZKP) [66]. In this method, one party (Prover) can prove that a specific statement is true to the other party (verifier) without disclosing any additional information. Zero Knowledge Encryption makes sure that no one, except you (not even the service provider or blockchain app development agency) can access your secured data.

The fifth most used consensus is Proof of Stake (PoS) (46). Due to the limitations of PoW as energy inefficiency, delay, and vulnerable to security threats, PoS has been developed enabling to achieve the consensus via proving the stake ownership. This mechanism is expected to become a cutting-edge technology for future blockchain networks [67].

**Table 9.** The most frequently used consensuses

| **Author keywords** | ***TP*** |
|---|---|
| Consensus or Algorithm or Protocol or Mechanism | 480 |
| Byzantine fault tolerance | 111 |
| Proof of Work | 101 |
| proof of Knowledge | 68 |
| Proof of Stake | 46 |
| Proof of Authority | 26 |
| Proof of Delivery | 3 |
| Proof of Location | 3 |
| Proof of Learning | 3 |
| Proof of Contribution | 2 |
| Algorand | 2 |

### 4.9. Sustainable and green blockchain

Blockchains are often stigmatized for their burden on the environment. While it is true that Bitcoin itself and similar proof-of-work (PoW) chains have a considerable ecological impact, proof-of-stake (PoS) chains are vastly more energy efficient. For example, the Ethereum network recently upgraded to PoS, which saw Ethereum's energy usage drop by 99.9% [68].

**Table 10.** The most used consensuses

| **Author keywords** | ***TP*** |
|---|---|
| Smart aspects | 519 |
| Energy aspects | 180 |
| Sustainability | 156 |
| Electric aspects | 146 |
| Ecosystem | 72 |
| Green aspects | 55 |
| Circular economy | 54 |
| Carbon aspects | 25 |
| Environment aspects | 22 |
| Climate | 12 |

There are multiplied efforts to make blockchain sustainable technology, table 10 shows the used keywords to encourage this environmental challenge. The keywords were summed manually by similar aspects, using our experience in the domain. Smart aspects (519) represents most keywords, like smart blockchain, smart home, smart grid, smart device, smart logistics, smart society…etc. All these smart aspects try to make all our society or environment smarter by giving them hard or soft tools to reason and make decisions autonomously to avoid harm the environment. Smart blockchain is a new generation of blockchain network that allows one or more than a smart contract. The decentralized system of smart contracts collects the data accurately and flawlessly. The decentralized nature of smart blockchain ensures that there is no single point of control or failure, making it resistant to tampering, hacking, and other malicious activities. Simultaneously this decentralization method helps store and register the data in new blocks. The complete process of a transaction is automatic, without any human interaction [69].
Energy aspects appear with great frequency (180), they include energy as a service, energy cost, energy blockchain, energy efficiency, energy financing, energy optimisation, energy saving, energy storage, energy trading etc. The blockchain is a big consumer of energy because of its mining process, the focus is more and more on reduce this consumption by the blockchain by proposing green consensuses like Proof of Stake.

The third most frequent aspect is sustainability (156), it means we have to use resources especially natural ones operational and not waste them to safeguard the health of the terrestrial globe now and to think to the sustainability of these resources for the next generations. This behaviour should take in consideration culture or society, economic efficiency and the environment. The sustainable blockchain is consuming less energy and tries to develop a reusable mining chip which is a hard waste not recyclable.

The electric aspects (146) encourage the consumption of electricity of pollutants as fuel and organic power.

An ecosystem (72) is a geographic area where plants, animals, and other organisms, as well as weather and landscapes, work together to form life [70]. It is integrated in the studied articles because of the nuisance of blockchain to this ecosystem to have to be respected by all the technologies.

Green aspects (55) are focused on greening all the processes in industries to be respectful to the environment and biodegradation of products in the nature.

Circular economy (54) ai all what is related to profitably recycling products.

Carbon aspects (25) have to measure the footprint of all technologies and processes and reduce it to lead it to the allowed worldwide standards.

Environment aspects (22) and the climate aspects (12) are encouraging to be environment-friendly intra-entreprise or extra-enterprise and at all the stages of life cycle of the product or process.

### 4.10. Medical blockchain

The medical aspects were strongly present in the collection of studied articles, we found 418 keywords related to medical aspects among 15386 keywords. It is suitable to draw attention that the medical area benefits to all offered technologies as blockchain. Before treating keywords, we will look on titles of articles, we found that the word health appears 497 times, medical appears 230 times, hospital appears 15 times and patient appears 60 times. These numbers give an idea about the emergence of blockchain in medical or healthcare in general.

Table 11 illustrates the most used author keywords. The electronic health record and data appears 200 times to demonstrate the importance of the data of patient and their privacy and confidentiality. The blockchain represents a good technology to guarantee the secure access. The question is «Who can access to these records»?, the medical staff or the patient? The rules differ from a medical system to another. Medical services (105), e-health aspects (105) and healthcare aspects (89) are related to the electronic healthcare systems encouraging the telemedicine and offer a remote support of patients who are spared from moving to the hospital. Intenet of medical things (72) are the sensors used on the body of a patient to measure certain characteristics like temperature, pressure, glycemia,…etc, to inform servers or medical staff to intervene or to autoregulate these measures injecting the appropriate drugs in the body by devices on the body of the patient. Pandemic aspects (71) are also treated because of the harmful after-effects of Covid-19 last years and its enhancement of the use of eHealth systems securely with the blockchain technology.

**Table 11**. The most used health keywords

| **Author keywords** | ***TP*** |
|---|---|
| Electronic health record aspects or data | 200 |
| Medical services | 142 |
| e-Health aspects | 105 |
| Healthcare aspects | 89 |
| Internet of medical things | 72 |
| Epidemic or pandemic or disease | 71 |
| Medical blockchain | 55 |
| Biological aspects | 50 |
| Medical image | 48 |
| Hospital aspects | 37 |
| Forensic aspects | 35 |
| Pharmaceuticals and medical devices | 29 |
| Medical security and insurance | 28 |
| Patient centric | 20 |
| Medical logistic | 12 |
| Emergency aspects | 10 |
| Green healthcare | 6 |

Medical blockchain (55) pours directly in the importance of the blockchain technology in healthcare. The most cited article is [71]. The authors proposed a Healthcare Data Gateway (HGD) architecture based on blockchain to enable patient to own, control and share his or her own data easily and securely without violating privacy, which provides a new potential way to improve the intelligence of healthcare systems while keeping patient data private.

The remaining keywords are treating the limitroph aspects around the success of the blockchain technology in healthcare in general. There are several barriers to the use of blockchain like forensic aspects and the governance in multipartite of the blockchain.

### 4.11. Blockchain and cybersecurity

The blockchain is also used in to sensible sectors like banks, it can be applied in audit operations practically for unanticipated events which can emerge in cyberspace to mitigate inherent risk to residual levels. However, there is ample room to adapt this technology for cybersecurity management and audit practices from the point of view of the labour force, regulations and environmental issues [76].

Staff of companies using blockchain should be trained to intrusion detection and prevention policy for cybercrime [77].

## 5. CONCLUSION

This work is a bibliometric study of the emerging blockchain technology between 1992 and 2022. This choice is not arbitrary, it is due to the lack of such studies in the existing literature, in one hand, and, in the other hand, the importance of this technology for the huge gaining in transparency, security, privacy and immutability. This latter is the most important characteristic, because the blocks of information are added after validation by a consensus and could not be modified or removed. These characteristics are harmful to certain organisations which are not to this transparency in their business. 9107 articles were collected from the online version of the Science Citation Index Expanded (SCI-EXPANDED), the Clarivate Analytics Web of Science Core Collection database (data updated on 29 June 2023), using a combination of query keywords and Boolean operators containing variants of blockchain. This number is obtained after filtering the search removing no significant results. Several analyses are performed using bibliometrics indicators of productivity and citations or impact of production. Some manipulations were necessary to identify and adjust the affiliations of authors, to avoid scientific inflations.

The most used types of documents are articles because they contain basic and experiment studies and original ideas then and reviews because the importance of this type in paving the way for the novice researchers. The content of most three relevant reviews is resumed.

The scientific production and the citations are increasing over years, giving more attention and usability of the blockchain.

The productive Web of Science productive categories are: (1) information systems computer science, (2) electrical and electronic engineering, (3) telecommunications and (4) theory and methods computer science. The nature of the blockchain does so it is taken in account by information and communication fields.
The productive journals in blockchain are: (1) *IEEE Access*, (2) *IEEE Internet of Things Journal*, (3) *Sensors* and (4) *Sustainability*. It is comprehensible when the Internet of Things are more and more combined to the blockchain to make basical information more reliable coming from connected devices. The sustainability is strongly introduced because of the energy consuming of blockchain and the researchers look for green consensuses of mining to minimize this consumption.

The countries having the higher production are China, USA, India, South Korea and the UK, via their institutions representing of centers of excellence in the domain.

The Chinese institutions are the pioneers in the domain of blockchain (BUPT university, Chinese Academy of Sciences), then comes the Indian Thapar Institute of Engineering and Technology and the Saoudian King Abdulaziz university.

Resumed contents of the top 10 cited articles are presented to enrich the bibliometric study by a breach of contents adding value and comprehension. The citations approximatively follow three different periods, a weak beginning period, a strong period and then a final weak period.

According to the author keywords, The trends are about (1) the security of the blockchain face the malicious intrusions especially in health records of patients and the diversion of cryptocurrencies' transactions, (2) the Internet of Things as physical connected devices measuring situations and in certain cases regulating the flaws if they are smart ones, (3) the use of smart contracts especially in the non monatery applications as blockchain education to save credentials and certificates, (4) the most used cryptocurrency is still the bitcoin.

As important component of blockchain, special attention is given to consensuses used for tne process of mining or validating a block of transactions before adding it to a blockchain, the most used is Byzantine fault tolerance resisting in malicious situations, Proof Of Work consuming time and energy, proof of Knowledge minimizing thz number of provers and Proof Of Stake minimizing time and energy.

Another aspect is studied, how much the blockchain is aligning with the green philosopy ?. Because of its great consumption of energy, blockchain is integrated in the use renewable energies and circular economy trying to find a susbstitution to its non-recyclable ship used in mining.

As an example of fields using the blockchain is the medical one, using body sensors helping in tele-diagnosis and auto regulation by injecting substances in the body.

This study is useful to scientific community in need to know statistical indexes concerning blockchain technology since its birth, its possibilities of use in the majority of domains and certain barriers to its use like its high cost, absence of skilled staff to manage it, absence of law regulating its use and the governance of the blockchain in interoperable context between partners of blockchain.

Among the limitations of the study, self-citations are not distinguished from the remaining citations which could braise even by a small percentage the real impact of an article. The research query is performed on all fields of the articles (titles, abstracts and the body of the article), which affects somewhat the relevancy of some articles related to a blockchain notion existing in chemical field concerning the structure of polymers.

Future research would be (1) on consensuses less consuming energy, using the renewable energies, in a philosophy of greening the blockchain, (2) disclosing the usability of blockchain in all domains, (3) design of a battery of laws to help governments to adopt this technology with the slightest risk, (4) guaranteeing the privacy and determining the new roles and responsibilities of the users of blockchain.

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