A Bibliometric Analysis of Highly Cited and High Impact Blockchain Publications

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***Abstract*— The blockchain technology has been around for two decades already. It is not largely used because it is not enough known by businesses and its cost is still high relatively. It represents one of the emergent technologies of the fourth industrial revolution reinforcing the digitalisation of businesses by smart contracts and cryptocurrencies, handling monetary and non-monetary transactions. To show its advances in researches, a bibliometric study is performed using articles selected by citations from Web of Science database. The sample is the 100 top cited articles. Citations' indexes are calculated (total, by year, total and their average). *Y*-index is used to evaluate publication performance of authors and rank them. The most productive and cited journals, institutions and countries are identified. The most cited articles and their categories are found. There are several practical implications of this study; it offers a guideline to researchers to determine the most impacting authors, institutions, countries and articles in the domain of blockchain technology. It also helps to know the trends overtime of the blockchain.**

Keywords*— *Blockchain; web of science; Scientometrics analysis; bibliometric analysis; High Impact Blockchain Publications; Highly Cited Blockchain Publications.

I. INTRODUCTION

The blockchain technology is a database shaped in a chain of blocks, in a peer to peer network, where all allowed partners can add information concerning their partnership information or transactions without an intermediate. The modification and suppression are not allowed in a blockchain. Miners are the nodes of the network who validate the candidate block representing the added information. These miners are in competition to retrieve the hash of the block to get a reward. All the data in the blocks are encrypted to ensure more security of the data.

This technology could be used practically for monetary or non-monetary purposes. The use of blockchain fosters security against the hack of private data and its modification or suppression. This data is protected by the private and public keys used for decryption of data by the recipient. The electronic signature of data or document allowed by complicated functions of hash is a manner to authenticate the document when it is received.

The absence of intermediates in a blockchain network, helps to gain time in transactions and decrease costs of intermediation, since the network is confident. The blockchain could be applied in all industries; some of them retain the traditional databases and add a blockchain to save the sensible data, to decrease calculations of hashes and the consummation of energy. There is little bibliometric study of blockchain treating it in its generic aspect [1]. This paper will address this lack, using papers extracted from Web of Science database [2] and applying some bibliometric indicators.

The paper is structured as follows: Section II presents the set of used indicators or indexes for papers, authors, institutions and countries in the domain of blockchain. Section III is a comparative study between the found values of indicators. We will finish by a conclusion in Section IV.

II. METHODOLOGY

Document type of articles used in this study were retrieved from the Clarivate Analytics Web of Science Core Collection, the online version of the Science Citation Index Expanded (SCI-EXPANDED) (data updated on 14 May 2023). 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.

The total citations from Web of Science Core Collection received since publication year till the end of the most recent year of 2022 (TC2022) [3] was used. Articles with TC2022 of 100 or more were selected as highly cited publications [4]. A total of 306 highly cited blockchain articles were found in SCI-EXPANDED from 1991 to 2022. It was pointed out that documents only searched out by Keywords Plus are irrelevant to the search topic [5]. Ho's research group firstly proposed the "front page" as a filter including the article title, abstract, and author keywords [6]. The full record in SCI-EXPANDED and the number of citations in each year for each document were checked and downloaded into Excel Microsoft 365, and additional coding was manually performed [7]. Finally, 296 articles (97% of 306 articles) including search keywords in their "front page" were defined as highly cited blockchain articles. The journal 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, we used the term corresponding author [8]. Single authors in articles with unspecified authorship were both the first as well as corresponding authors [9]. 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. Affiliations in England, Scotland, North Ireland (Northern Ireland), and Wales were reclassified as being from the United Kingdom (UK) [10].

Publications were assessed using following citation indicators:

C_{year}: the number of citations from Web of Science Core Collection in a particular year (e.g. C2022 describes citation count in 2022) [11].

TC_{year}: the total 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}) [6].

CPP_{year}: average number of citations per publication ($CPP_{2022} = TC_{2022}/TP$), *TP*: total number of publications [12].

Y-index was used to evaluate publication performance of authors. The *Y*-index is defined as [11] [9]:

Y-index (*j*, *h*)

where *j* is a constant related to the publication potential, the sum of the first-author articles and the corresponding-author articles; and *h* is a constant related to the publication characteristics, polar angle about the proportion of *RP* to *FP*.

The greater the value of *j*, the more the first- and corresponding-author contributes to the articles.

$h = \pi/2$, indicates an author that has only published corresponding-author articles, *j* is the number of corresponding-author articles (*RP* > 0 and *FP* = 0);

$\pi/2 > h > \pi/4$ indicates that an author has more corresponding-author articles than first-author articles (*FP* > 0);

$h = \pi/4$ indicates that an author has the same number of first- and corresponding-author articles (*FP* > 0 and *RP* > 0);

$\pi/4 > h > 0$ indicates an author with more first-author articles than corresponding-author articles (*RP* > 0);

$h = 0$, indicates that an author has only published first-author articles (*FP* > 0 and *RP* = 0).

III. Results and Discussion

This section will explain the found results by the bibliometric analysis performed on the set of selected articles.

A. Characteristics of publication outputs

Figure 1 shows the distribution of the highly cited articles. The most 100 highly cited articles were published in 2019. In 2016 with seven articles had the greatest CPP_{2022} of 537 which could be attributed to the most frequently cited blockchain article entitled "Blockchains and smart contracts for the internet of things" [13] with a TC_{2022} of 1,782.

In 1991, CPP_{2022} was 402 attributed to the only article entitled "Ordered structure in mixtures of a block copolymer and homopolymers. 1. Solubilization of low-molecular-weight homopolymers" [14] published in 1991.

B. Web of Science Category and Journal

In 2021, Journal Citation Reports (JCR) indexed 9,649 journals with citation references across 178 Web of Science categories in SCI-EXPANDED.

Total 106 journals published highly cited articles related to blockchain in 45 Web of Science categories in SCI-EXPANDED mainly in information systems computer science with 114 articles (39% of 296 articles), immunology with 150 articles (10%), telecommunications with 104 articles (35%), and electrical and electronic engineering with 97 articles (33%).

It should be noticed that journals could be classified in two or more categories in Web of Science Core Collection, for instance *IEEE Access* was classified in information systems computer science, electrical and electronic engineering, and telecommunications, thus the sum of percentages was greater than 100% [4]. A fuzzy classification of journals could be a pertinent solution for the scientific database or in bibliometric study's authors should consider only one class, but the results will be biased.

Six of the 106 journals had 10 highly cited articles or more, including *IEEE Access* (IF_{2021} = 3.476) with 36 articles (12% of 296 articles), *IEEE Transactions on Industrial Informatics* (IF_{2021} = 11.648) with 22 articles (7.4%), *IEEE Internet of Things Journal* (IF_{2021} = 10.238) with 19 articles (6.4%), *IEEE Communications Surveys and Tutorials* (IF_{2021} = 33.840) with 14 articles (4.7%), *Future Generation Computer Systems-the International Journal of Escience* (IF_{2021} = 7.307) with 12 articles (4.1%), and *International Journal of Production Research* (IF_{2021} = 9.018) with 10 articles (3.4%). According to IF_{2021}, the top three journals have an IF_{2021} of more than 30 were the *Nature* (IF_{2021} = 69.504) with one article, the *Joule* (IF_{2021} = 46.048) with one article, and the *IEEE Communications Surveys and Tutorials* (IF_{2021} = 33.840) with 14 articles.

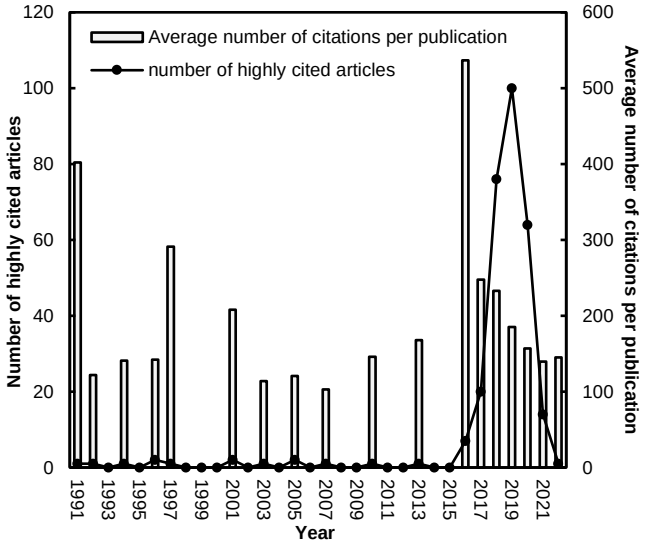

Figure 1. Number of blockchain articles and their average citations per publication by year.

C. Publication performances: countries and institutions

There was one highly cited blockchain articles (0.34% of 296 articles) without affiliations in SCI-EXPANDED. A total of 295 highly cited articles were published by authors affiliated from 53 countries including 125 single-country articles (42% of 1,507 articles) published by authors from 24 countries and 170 internationally collaborative articles (58%) published by authors from 52 countries. Six publication indicators [14] were applied to compare the top 15 productive countries (Table 1).

China dominated in five of the six publication indicators with a *TP* of 136 articles (46% of 295 articles), an *IPC* of 41 articles (33% of 125 single-country articles), an *ICP* of 95 articles (56% of 170 internationally collaborative articles), an *FP* of 114 articles (39% of 295 first-author articles), an *RP* of 99 articles (34% of 293 corresponding-author articles), while the USA ranked top with an *SP* of four articles (40% of 10 single-author articles).

At the institutional level, the determined institution of the corresponding author might be a home base of the study or origin of the paper [11]. Concerning institutions, 65 blockchain articles (22% of 295 articles) originated from single institutions, 60 articles (20%) were national collaborations, and 170 articles (58%) were international collaborations. Seven publication indicators [15] were applied to compare the top 16 productive institutions (Table 2). Out of the top 16 institutions, nine were in China, while the remaining seven were spread across the globe, with two in the USA, and one each in Singapore, Saudi Arabia, Canada, Australia, and Norway.

TABLE I. TOP 15 PRODUCTIVE COUNTRIES.

Country	*TP*	*TP* (%)	IP_C (%)	*ICP* (%)	*FP* (%)	*RP* (%)	*SP* (%)
China	136	1 (46)	1 (33)	1 (56)	1 (39)	1 (34)	2 (10)
USA	86	2 (29)	2 (23)	2 (34)	2 (13)	2 (14)	1 (40)
UK	32	3 (11)	5 (4.0)	3 (16)	4 (4.1)	5 (4.4)	N/A
Australia	31	4 (11)	3 (5.6)	4 (14)	3 (5.1)	3 (7.2)	2 (10)
Singapore	21	5 (7.1)	N/A	5 (12)	7 (3.7)	10 (2.4)	N/A
Canada	21	5 (7.1)	16 (0.80)	6 (12)	24 (0.34)	7 (2.7)	N/A
India	20	7 (6.8)	10 (1.6)	7 (11)	4 (4.1)	10 (2.4)	N/A
South Korea	18	8 (6.1)	3 (5.6)	8 (6.5)	4 (4.1)	4 (5.1)	N/A
Italy	14	9 (4.7)	7 (3.2)	10 (5.9)	7 (3.7)	6 (3.8)	N/A
Japan	13	10 (4.4)	5 (4.0)	14 (4.7)	10 (2.4)	12 (2.0)	N/A
Germany	11	11 (3.7)	16 (0.8)	10 (5.9)	9 (2.7)	7 (2.7)	N/A
Taiwan	11	11 (3.7)	10 (1.6)	12 (5.3)	12 (1.4)	12 (2.0)	2 (10)
Norway	11	11 (3.7)	N/A	8 (6.5)	24 (0.34)	7 (2.7)	N/A
France	10	14 (3.4)	10 (1.6)	14 (4.7)	11 (2.0)	14 (1.7)	N/A
Saudi Arabia	9	15 (3.1)	N/A	12 (5.3)	13 (1.0)	15 (1.4)	N/A

TP: total number of highly cited articles; *TP R* (%): rank of percentage of total number of articles in all articles; IP_C *R* (%): rank and percentage of single-country articles in all single-country articles; *ICP 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; N/A: not available.

The Beijing University of Posts and Telecommunications in China ranked the top with a *TP* of 14 articles (4.7% of 295 articles) and an *FP* of 10 articles (3.4% of 295 first-author articles) while the Beijing Institute of Technology in China ranked the top with an *RP* of nine articles (3.1% of 293 corresponding-author articles). The Worcester Polytechnic Institute in USA ranked the top with an IP_I of three articles (4.6% of 65 single-institution articles). The Kyoto University in Japan had three highly cited articles all of which were single-institution articles. The Hong Kong Polytechnic University in China ranked the top with an *NCP* of five articles (8.3% of 60 nationally collaborative articles) and an *SP* of one article (10% of 10 single-author articles). Only 12 institutions published single-author articles respectively. The Hong Kong Polytechnic University was the only one ranked in the top 16 in total highly cited articles. The Nanyang Technological University in Singapore ranked the top with an *ICP* of 13 articles (7.6% of 170 internationally collaborative articles). Only two of the nine institutions in China the Hong Kong Polytechnic University and the Xidian University had single-institution articles.

TABLE II. TOP 16 PRODUCTIVE INSTITUTIONS.

Institution, Country	*TP*	*TP* *R* (%)	IP_I *R* (%)	*NCP* *R* (%)	*ICP* *R* (%)	*FP* *R* (%)	*RP* *R* (%)	*SP* *R* (%)
Beijing University of Posts and Telecommunications, China	14	1 (4.7)	N/A	6 (3.3)	2 (7.1)	1 (3.4)	2 (2.4)	N/A
Nanyang Technological University, Singapore	13	2 (4.4)	N/A	N/A	1 (7.6)	2 (3.1)	5 (1.7)	N/A
University of Electronic Science and Technology of China, China	12	3 (4.1)	N/A	6 (3.3)	3 (5.9)	4 (2.7)	5 (1.7)	N/A
Hong Kong Polytechnic University, China	12	3 (4.1)	8 (1.5)	1 (8.3)	6 (3.5)	4 (2.7)	13 (1.0)	1 (10)
University of Oslo, Norway	10	5 (3.4)	N/A	N/A	3 (5.9)	N/A	2 (2.4)	N/A
Academy of Sciences, China	10	5 (3.4)	N/A	2 (6.7)	6 (3.5)	7 (1.7)	8 (1.4)	N/A
Guangdong University of Technology, China	9	7 (3.1)	N/A	2 (6.7)	13 (2.9)	6 (2.0)	8 (1.4)	N/A
Beijing Institute of Technology, China	9	7 (3.1)	N/A	6 (3.3)	5 (4.1)	2 (3.1)	1 (3.1)	N/A
University of Texas San Antonio, USA	8	9 (2.7)	8 (1.5)	19 (1.7)	6 (3.5)	16 (0.68)	8 (1.4)	N/A
Shanghai Jiao Tong University, China	8	9 (2.7)	N/A	6 (3.3)	6 (3.5)	8 (1.4)	4 (2.0)	N/A
University of Academy of Sciences, China	7	11 (2.4)	N/A	4 (5.0)	17 (2.4)	N/A	45 (0.34)	N/A
Worcester Polytechnic Institute, USA	7	11 (2.4)	1 (4.6)	6 (3.3)	40 (1.2)	8 (1.4)	8 (1.4)	N/A
University of Technology Sydney, Australia	6	13 (2.0)	N/A	N/A	6 (3.5)	38 (0.34)	20 (0.68)	N/A
Xidian University, China	6	13 (2.0)	3 (3.1)	N/A	17 (2.4)	12 (1.0)	8 (1.4)	N/A
King Saud University, Saudi Arabia	6	13 (2.0)	N/A	N/A	6 (3.5)	38 (0.34)	13 (1.0)	N/A
Carleton University, Canada	6	13 (2.0)	N/A	N/A	6 (3.5)	N/A	20 (0.68)	N/A

TP: total number of highly cited articles; *TP R* (%): rank of percentage of total number of articles in all articles; IP_I *R* (%): rank and percentage of single-institution articles in all single-institution articles; *NCP R* (%): rank and percentage of nationally collaborative articles in all nationally collaborative articles; *ICP 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; N/A: not available.

D. Publication performances: authors

Table 3 lists the top 15 most productive authors with five highly cited blockchain articles or more. Y. Zhang was the most productive author with 16 highly cited articles including two first-author articles, nine corresponding-author articles. Y. Zhang also ranked the top in corresponding-author articles. T.M. Choi and J.W. Kang with six highly cited articles published the most five first-author articles, respectively. T.M. Choi was also the only author had singly-author articles in the top 123 productive authors. Eight of the 15 productive authors including Y. Zhang, L.H. Zhu, J.H. Park, T.M. Choi, Z.H. Xiong, J.W. Kang, P.K. Sharma, and K.K. Gai were found to be the top 15 publication potential authors as evaluated by Y-index.

In the total of 290 highly cited blockchain articles (98% of 296 highly cited articles) had both first and corresponding authors information in SCI-EXPANDED, were extensively investigated based on the *Y*-index. The 290 highly cited blockchain articles were contributed by 1,061 authors in which 664 authors (63% of 290 authors) had no first- and no corresponding-author articles with *Y*-index (0, 0); 144 (14%) authors published only corresponding-author articles with $h = \pi/2$; 12 (1.1%) authors published more corresponding-author articles than first-author articles with $\pi/2 > h > \pi/4$ ($FP > 0$); 98 (9.2%) authors published the same number of first- and corresponding-author articles with $h = \pi/4$ ($FP > 0$ and $RP > 0$); 7 (0.66%) authors published more first-author articles than corresponding-author articles with $\pi/4 > h > 0$

($RP > 0$); and 136 (13%) authors published only first-author articles with $h = 0$.

TABLE III. TOP 15 PRODUCTIVE AUTHORS WITH FIVE HIGHLY CITED ARTICLES OR MORE

Author	rank (*TP*)	rank (*FP*)	rank (*RP*)	rank (*SP*)	*h*	rank (*j*)
Y. Zhang	1 (16)	7 (2)	1 (9)	N/A	1.352	1 (11)
D. Niyato	2 (9)	N/A	N/A	N/A	0	398 (0)
L.H. Zhu	3 (8)	26 (1)	2 (5)	N/A	1.373	2 (6)
J.H. Park	4 (7)	26 (1)	2 (5)	N/A	1.373	2 (6)
J. Sarkis	4 (7)	N/A	7 (2)	N/A	π/2	31 (2)
K.K.R. Choo	4 (7)	N/A	5 (3)	N/A	π/2	19 (3)
Z.H. Xiong	7 (6)	7 (2)	5 (3)	N/A	0.9828	5 (5)
F.R. Yu	7 (6)	N/A	7 (2)	N/A	π/2	31 (2)
S. Maharjan	7 (6)	N/A	N/A	N/A	0	398 (0)
J.W. Kang	7 (6)	1 (5)	N/A	N/A	0	5 (5)
T.M. Choi	7 (6)	1 (5)	33 (1)	1 (1)	0.1974	2 (6)
P.K. Sharma	12 (5)	3 (4)	33 (1)	N/A	0.245	5 (5)
V.C.M. Leung	12 (5)	N/A	33 (1)	N/A	π/2	138 (1)
K.K. Gai	12 (5)	3 (4)	33 (1)	N/A	0.245	5 (5)
M. Guizani	12 (5)	N/A	N/A	N/A	0	398 (0)

TP: total number of highly cited articles; *FP*: first-author articles; *RP*: corresponding-author articles; *SP*: single-author articles; *j*: a *Y*-index constant related to the publication potential; *h*: a *Y*-index constant related to the publication characteristics; N/A: not available.

In the polar coordinates (Figure 2), the distribution of the *Y*-index (*j*, *h*) of the leading 137 potential authors in blockchain research with $j \geq 2$ was demonstrated. Every point has a coordinate *Y*-index (*j*, *h*) that could symbolize a single author or multiple authors, for example, X.H. Huang, Y.H. Zhang, L.D. Xu, S. Saberi, K. Salah, M. Holbl, C. Liu, M.S. Hossain, F.J. Luo, K. Fan, and other 80 authors who published only one highly cited article with *Y*-index (2, π/4). Y. Zhang with *Y*-index (11, 1.352) had the greatest publication potential in highly cited blockchain articles (did not show in the figure), followed distantly by L.H. Zhu (6, 1.373), J.H. Park (6, 1.373), and T.M. Choi (6, 0.1974) respectively. Zhu and Park had the same *Y*-index shows that they have the same publication potential and the publication characteristics. Zhu, Park, and Choi had the same *j* of 6.

These authors are located on the same curve ($j = 6$) in Figure 2, indicating that they had the same publication potential in blockchain research with a *j* of 6 but different publication characteristics (Ho and Hartley, 2016b).

Zhu and Park published more corresponding-author articles than first-author articles with an *h* of 1.373 while Choi published more first-author articles than corresponding-author articles with an *h* of 0.1974. Similarly, K.K.R. Choo with *Y*-index (3, π/2); Z. Su, M. Shen, A. Zhang, Q. Xia, Y. Yuan, D. Ivanov, and S. Ding with the same *Y*-index (3, 1.107); Z.B. Zheng, J. Wang, and B. Cao with the same *Y*-index (3, 0.4636); and M.T. Liu (3, 0) are located on the same curve with *j* of 3.

These authors had the same publication potential with an *j* of 3 but different publication characteristics. Choo published only three corresponding-author articles with an *h* of π/2. Su, Shen, Zhang, Xia, Yuan, Ivanov, and Ding had higher ration of corresponding-author articles to first-author articles with an *h* of 1.107. Zheng, Wang, and Cao had higher ration of first-author articles to corresponding-author articles with an *h* of 0.4636. Finally, Liu published only three first-author articles with an *h* of 0. Similar situation for authors located on *j* of 5, 4, and 2 was also found. W. Viriyasitavat, P. Zhang, M. Ul Hassan, N. Kshetri, A. Dorri, M.A. Ferrag, I. Eyal, and C. Esposito with the same *Y*-index (4, π/4) and X.H. Huang and other 89 authors with the same *Y*-index (2, π/4) are located on the diagonal line ($h = \pi/4$) indicating that they had the same publication characteristics but different publication potential.

Viriyasitavat and other seven authors had the greatest publication potential with a *j* of 4 followed by Huang and other 89 authors with a *j* of 2. K.K.R. Choo with *Y*-index (3, π/2) and Y.L. Teng, J.Y. Wang, J. Weng, K. Wang, X.N. Wang, J. Ren, D.I. Kim, M. Kraft, J. Sarkis, F.R. Yu, and P. Wang with the same *Y*-index (2, π/2) are located on the straight line (y-axis with $h = \pi/2$) had the same publication characteristics. Choo had higher publication potential with a *j* of 3 than others with a *j* of 2. Similarly, J.W. Kang (5, 0), M.T. Liu (3, 0), and S. Wang, Y. Xu, Z. Li, J.W. Leng, W. Liang, and Y.L. Lu with the same *Y*-index (2,0) are located on the straight line (x-axis with $h = 0$) also had the same publication characteristics. Kang had the greatest publication potential with a *j* of 5, followed by Liu with a *j* of 3 and Wang, Xu, Li, Leng, Liang, and Lu with a *j* of 2.

The location on the graph along with one of the curves or along a straight line from the origin represents different families of author publication potential or publication characteristics, respectively. A potential for bias in the analysis of authorship might attributes to different authors having the same name, or the same author using different names over time, especially for Chinese authors [8].

E. The top ten most frequently cited articles in blockchain research

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 until to the end of the most recent year of 2022 (TC_{2022}) was applied to improve the bias using data from the database directly [3]. A total of 245 articles (83% of 296 articles), 279 articles (96% of 291 articles with abstract in SCI-EXPANDED), and 242 articles (93% of 261 articles with author keywords in SCI-EXPANDED) contain search keywords in their title, abstract, and author keywords respectively. Table 4 shows the top 10 most frequently cited articles on blockchain research.

The top ten articles were published from 2016 to 2019. Articles by Xu et al. (2018) and Tschorsch and Scheuermann (2016) only contained search keywords in the author keywords. Article by Mengelkamp et al. (2018) contained search keywords in search keywords in the author keywords and abstract. Seven of the top ten articles contained search keywords in the title, abstract, and author keywords. These articles are directly related to blockchain research. Citations of a highly cited article are not always high [4]. It is necessary to understand citation history of a classic article. The citation histories of the top ten blockchain articles are shown in Figure 3. Articles by [13], Xu et al. (2018), Zheng et al. (2018), and Saberi et al. (2019) had sharper citation increasing after their publication. However, all the top articles had citation decreasing after three years. Blockchain is a nascent research topic, and in its initial stages, subjects are being explored and refined through testing.

The highly cited articles were not only the most frequently cited but also the most impactful in the recent

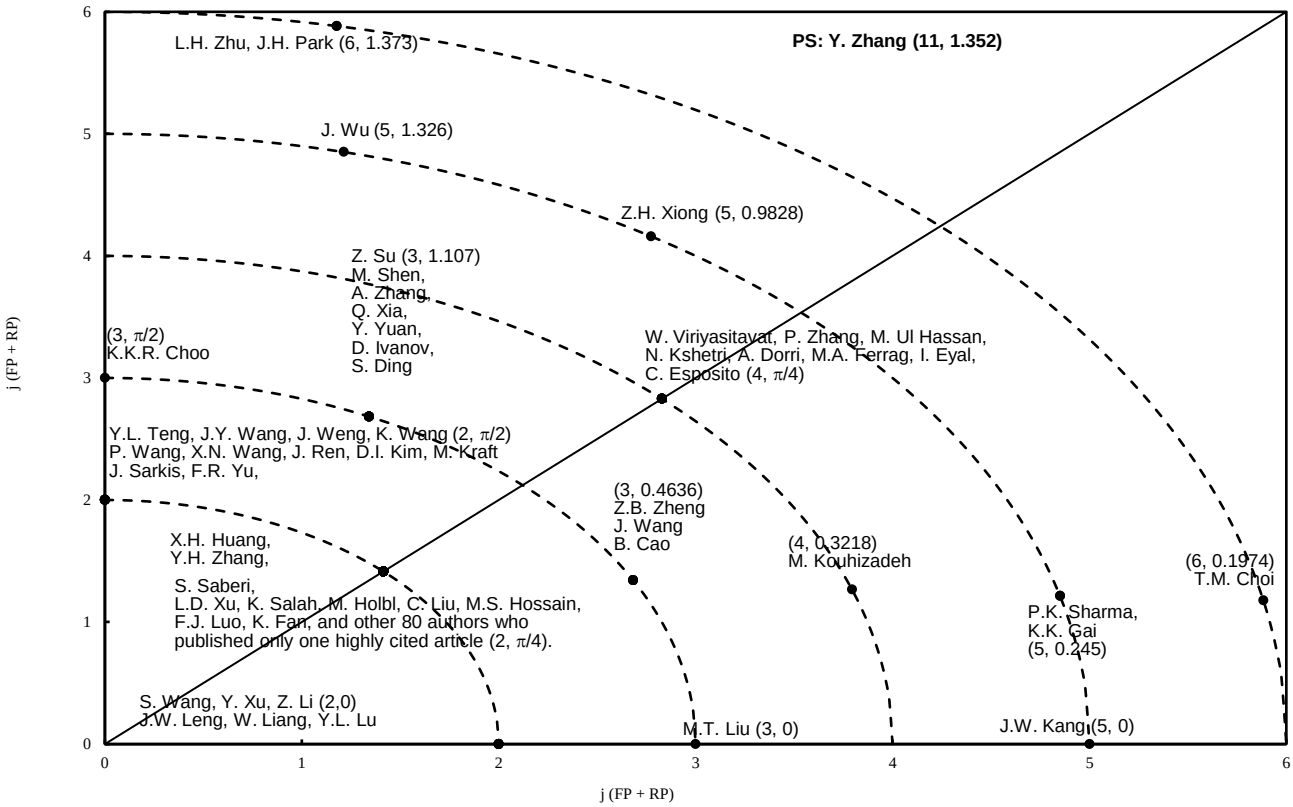

Figure 2. Top 137 authors with Y-index (j ≥ 2).

year 2022 in blockchain research. Six of the top ten most impactful articles were also ranked in the top ten most frequently cited were summarized as:

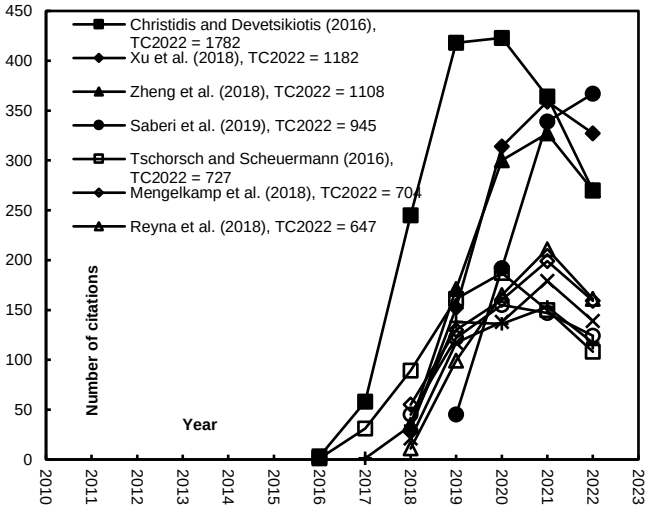

Figure 3. The citation histories of the top ten most frequently cited articles on blockchain research.

- Blockchain technology and its relationships to sustainable supply chain management [16], the articles published by four authors from the Worcester Polytechnic Institute in the USA with a TC_{2022} of 367 (rank 1st in blockchain research) and a TC_{2022} of 945 (rank 4th).
- Industry 4.0: state of the art and future trends [17], the articles published by three authors from the Old Dominion University and the University of Minnesota in the USA with a C_{2022} of 327 (rank 2nd in blockchain research) and a TC_{2022} of 1,182 (rank 2nd).
- Blockchains and Smart Contracts for the Internet of Things [13], the articles published by two authors from the North Carolina State University in the USA with a C_{2022} of 270 (rank 3rd in blockchain research) and a TC_{2022} of 1,782 (rank 1st).
- Blockchain challenges and opportunities: a survey [18], the articles published by five authors from the Sun Yat Sen University, the Macau University of Science and Technology, and the National University of Defense Technology in China with a C_{2022} of 270 (rank 3rd in blockchain research) and a TC_{2022} of 1,108 (rank 3rd).
- On blockchain and its integration with IoT. Challenges and opportunities [20], the articles published by five authors from the University of Malaga in Spain with a C_{2022} of 161 (rank 8th in blockchain research) and a TC_{2022} of 647 (rank 7th).
- Designing microgrid energy markets A case study: The Brooklyn Microgrid [21], the articles published by six authors from the Karlsruhe Institute of Technology in Germany and L03 Energy in the USA with a C_{2022} of 159 (rank 9th in blockchain research) and a TC_{2022} of 704 (rank 6th).

IV. CONCLUSION

The conducted bibliometric study about the blockchain in this paper allowed the calculation of several bibliomtric indicators to rank authors, countries, institutions, articles and their categories according to the database, using essentially the scientific impact on scientific community. It offers a guide for novel scientific researchers on the technology blockchain to know the authors and institutions pioneers in the domain, to establish synergies and collaborations.

TABLE IV. THE TOP TEN MOST FREQUENTLY CITED ARTICLES IN BLOCKCHAIN RESEARCH

Rank (TC_{2022})	Rank (C_{2022})	Title	Country
1 (1,782)	3 (270)	Blockchains and smart contracts for the internet of things [13]	USA
2 (1,182)	2 (327)	Industry 4.0: State of the art and future trends [17]	USA
3 (1,108)	3 (270)	Blockchain challenges and opportunities: A survey [18]	China
4 (945)	1 (367)	Blockchain technology and its relationships to sustainable supply chain management [16]	USA
5 (727)	28 (108)	Bitcoin and beyond: A technical survey on decentralized digital currencies [19]	Germany
6 (704)	9 (159)	Designing microgrid energy markets A case study: The Brooklyn Microgrid [21]	Germany, USA
7 (647)	8 (161)	On blockchain and its integration with loT. Challenges and opportunities [20]	Spain
8 (599)	18 (124)	Security and privacy in decentralized energy trading through multi-signatures, blockchain and anonymous messaging streams [22]	U Arab Emirates
9 (594)	13 (139)	Consortium blockchain for secure energy trading in industrial internet of things [23]	China, Norway
10 (579)	23 (117)	Enabling localized peer-to-peer electricity trading among plug-in hybrid electric vehicles using consortium blockchains [24]	China, Norway, Canada

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.

This study helps to know how the researches are in advance about the blockchain to encourage businesses to invest in it and gain security of data, transparency and efficiency of the information system.

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