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# Decentralized finance: a comparative bibliometric analysis in the Scopus and WoS databases

Gülcihan Aydaner<sup>1\*</sup> and H. Aydın Okuyan<sup>2</sup>

## Abstract

DeFi blockchain technology, known as decentralized finance today, separates from the traditional financial ecosystem and ushers the new financial landscape onto digital platforms. In decentralized financial applications, all digital assets are safeguarded by blockchain technology. Thanks to this technology, investors can transfer their financial assets without being dependent on banking authorities. Despite the numerous advantages they bring, financial assets based on the decentralized finance ecosystem come with certain disadvantages. These assets are difficult to control, easily manipulated, and are at risk due to their vulnerability to cyberattacks. This study conducted bibliometric analyses on a total of 930 publications registered in the Web of Science (WoS) and Scopus databases using the VOSviewer program. In both databases, “all fields” were filtered and scanned with the keyword “decentralized finance.” According to the results, the Scopus database has much richer content compared to the WoS database. The most cited author in the Scopus database was Chen Y, while in the WoS database, it was Nakamoto S. There has been a significant increase in the number of publications in both databases since 2020. Additionally, it was detected that the most cited countries in both databases were the USA, China and England, respectively. It has been observed that computer science comes to the fore in the publication rankings. Decentralized finance is an interdisciplinary field of study. Therefore, many more qualified hybrid studies are needed. More studies are needed, especially examining investor behavior. The analyses presented in this article will enable researchers to grasp the bigger picture from a holistic perspective.

**Keywords** Decentralized finance, DeFi, Blockchain, Bibliometric analysis, Overlap, WoS, Scopus

## Introduction

Decentralized finance has emerged as one of the most frequently discussed topics in recent years. Upon reviewing the literature, it becomes evident that decentralized finance began garnering attention, particularly after the 2008 financial crisis, and this

interest in the subject has continued to grow with each passing year. In recent years, DeFi platforms have been exposed to cyberattacks, causing DeFi investors to lose millions of dollars [23]. Despite all the losses, it is known that over billions of dollars of assets are locked on these platforms. For example, Aave V2, Uniswap, Compound, and Balancer are the largest DeFi platforms with a total value locked (TVL) of over \$12 billion [44]. According to the latest data, the number of cryptocurrency investors worldwide reached 425 million in 2022 [47]. According to January 2023 records, 22,249 cryptocurrencies are traded in the cryptocurrency market. The market value of these cryptoassets is \$851,752,614,081. The transaction volume is \$38,747,165,280. These data show

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that cryptocurrencies attract the attention of investors [34]. The research questions that should be asked based on this data are as follows: Is there an increase in DeFi publications in parallel with the increase in the number of DeFi investors? How much interest do academic communities show in decentralized finance?

The primary risks inherent in the decentralized financial ecosystem remain central to the debates surrounding decentralized finance. In a study by Bose et al. [13], systematic risks in financial markets related to the decentralized financial ecosystem were evaluated. The authors provided an in-depth analysis of the potentials and pitfalls of blockchain technology in ensuring financial sustainability. They elucidated the potential risks stemming from prevailing financial practices in the current financial ecosystem. Furthermore, they underscored that decentralized blockchain applications are poised to play a significantly larger role within the financial system. The term “DeFi,” derived from “Decentralized” and “Finance,” is a recurrent expression in the literature for all transactions pertaining to decentralized finance. Zetzsche et al. [52] underscored the significant advantages that DeFi technologies offer in the storage capacities of financial systems. They anticipated a decrease in centralization within financial services and noted that traditional centralized financial technologies and business models are inadequate to meet today’s financial needs. However, they also pointed out that DeFi, while valuable, may not fully address all financial requirements due to legal and regulatory challenges. According to these authors, the full integration of DeFi technologies into financial life faces certain legal difficulties.

In the view of Gramlich et al. [26], there is a pressing need for thorough research to explore how DeFi technologies can be effectively integrated into various institutions and structures. Schar [43] highlighted the significance of establishing asset management protocols and utilizing smart contracts to bolster the financial infrastructure of DeFi. The author acknowledged that while DeFi technologies present crucial opportunities in financial services, realizing these opportunities transparently hinges on mitigating DeFi’s inherent risks. Consequently, the reduction in risks relies on the establishment of solid foundations for smart contracts and DeFi management protocols.

Chen and Bellavitis [17] indicated that in the realm of decentralized finance, achieving stability in decentralized financial services remains challenging due to the surge in fraudulent activities and the limited involvement of supervisory institutions. They identified various factors that impede the ascent of decentralized finance, including the costs associated with maintaining trust on platforms,

the potential privacy and confidentiality risks stemming from excessive transparency, the risk of rigidity due to the immutability of smart contracts, the absence of accountability in platforms, and the inability to publicly record transactions due to the unalterable nature of the blockchain. Consequently, they argued that decentralized finance has yet to reach its potential and faces obstacles to progress.

Despite the aforementioned drawbacks, as highlighted by Stepanova and Erins [45], a robust trend has emerged due to the growing interest in decentralized finance with the shift toward digital economies. Consequently, the grip of centralization on financial services will no longer enjoy a monopoly position Grassi et al. [27]. Remarkably, in 2020 alone, investments totaling at least \$15 billion poured into DeFi projects. Caldarelli and Ellul [15] as well as Bamakan et al. [10] accentuated the significance of digital-based intellectual property rights, underscoring the value of NFT (Non Fungible Tokens)-based patents, which leverage blockchain technology. These authors have delved into the conceptual framework of the NFT-based patent system, a cornerstone of intellectual property across various sectors within today’s digital landscapes. In a clearer sense, they have proposed remedies for safeguarding the intellectual property rights of blockchain technology in NFT-based innovations.

In recent years, researchers have begun to investigate whether renewable energy tokens can be an alternative investment instrument, especially in parallel with the increasing interest in renewable energy sources and green energy. In a study investigating the connection between renewable energy tokens and the BRICS stock market, it was detected that investors adding energy tokens to their portfolios provided significant advantages in diversifying their portfolios. Additionally, the average returns of green cryptocurrencies such as Cardano, IOTA, Stellar and Ripple have been suggested to be promising in portfolio diversification compared to G7 stocks [1, 1, 2, 2, 3, 3]. The results of a case study investigating the effects of the collapse of a Silicon Valley Bank show that investors can take refuge in safe havens such as oil, gold and cryptocurrencies [1–3]. Recent research shows that cryptocurrencies are an alternative to traditional stocks. The increase in the return rate of the S&P 500 stock index negatively affects cryptocurrency returns. Additionally, the prices of DeFi tokens are affected by tweet information [38]. The fact that behaviors affect the prices of cryptocurrencies is explained by the BeFi theory. BeFi investigates how psychological effects are reflected in the prices of assets. In the simplest terms, BeFi theory explains behavioral finance. Research on BeFi applied to DeFi has shown a rising trend in recent years [11]. Another issue that attracts the attention of DeFi

researchers is the relationship between decentralization and market value.

Considering the high information asymmetry in the crypto- and token markets, blockchain platform businesses in particular have important duties. Recent research shows that reveal and social media disclosures by blockchain platform businesses mediate the market cap relationship with DeFi [36].

This study involves the examination of academic research within the realm of decentralized finance structured by blockchain technologies through the utilization of bibliometric analysis. This analytical method offers a comprehensive approach to the subject matter by assessing the connections among publications using numerical data. It aids in bridging gaps in understanding the subject and facilitates the discovery of new research avenues [48]. Despite decentralized finance being among the most prominent topics in recent years, a literature review has revealed a lack of sufficient bibliometric research in this domain [5]. In addition, studies in the literature on the analysis of investor behavior in the cryptocurrency market are limited. [7]. Consequently, gaps exist within the academic literature concerning decentralized finance. Thus, this study conducts diverse bibliometric analyses encompassing 778 publications from the years 1991 to 2023, sourced from the Scopus database, along with 152 publications spanning the years 2010–2023, extracted from the Web of Science database. The subsequent section of the study outlines the research methodology, while the following segment presents assessments based on the findings derived from the bibliometric analysis. The fourth and fifth chapters are devoted to discussion and conclusions.

## Methodology

The bibliometric analysis method was initially introduced by Pritchard [40] and has since remained a frequently preferred quantitative analysis technique in subsequent years. The research data were sourced from the Web of Science and Scopus databases, and these were subsequently analyzed employing the VOSviewer program. The Web of Science and Scopus databases, from which the data were retrieved, rank among the most esteemed international databases [46]. The bibliometric analysis commenced with a database filtering process. Initially,

the “All Fields” option was selected within the Web of Science and Scopus databases. Subsequently, filtering was performed using the keyword “decentralized finance” enclosed in quotation marks. The analysis encompassed all the publications that met this criterion. All accessed publications were imported into the VOSviewer program and subjected to map-based analysis. Moreover, summary data were visualized using graphs and tables. A depiction of the research methodology is succinctly encapsulated in Table 1. Moreover, a diagram depicting the content of the methodology is included. The diagram is shown in Fig. 1. When both images are examined, it will be seen that the Scopus database is larger than the WoS database.

Table 1 shows that the first article on decentralized finance in the WoS database was written in 2010. This article argues that decentralized finance practices lead to financial inefficiency [32]. In the Scopus database, it is seen that the first article was published in 1991. The article written by Danso [19] describes hunger caused by the African economy and social crises.

This study employs nine guiding questions for the bibliometric analysis, which are displayed in Table 2.

The limitation of the research is that there are no similar numbers of data in the databases in comparative bibliometric analyses. Let us explain this constraint in detail. Since the Scopus database contains 5 times more data than the WoS database, we could not give the same commands to the program for some questions after transferring the data to the VOSviewer program. This was because the maps were not clear enough due to data compression and less data was visible on the maps. To put it more clearly, while entering commands into the VOSviewer program, we used different commands for WoS and Scopus in some questions to capture the map with the best view and the most data. For example, “What are the most commonly cited references?” While searching for an answer to the question, filtering was done by selecting a minimum of three citations from a reference source for WoS database and a minimum of five citations for Scopus database. The reason for different filtering in both databases is that the program presents a very shallow map when filtering with small numbers in the database containing larger data. Since the Scopus database is 5 times larger than the WoS

**Table 1** Research method

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### SEARCH RESULTS WITH THE KEYWORD “DECENTRALIZED FINANCE” IN APRIL 2023

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Filtered “All Fields” in the WoS database and searched for “decentralized finance”  
Bibliometric analyze started with 152 viewed publications published in 2010–2023

Filtered “All Fields” in the Scopus database and searched for “decentralized finance”  
Bibliometric analyzes were started with 778 viewed publications published in 1991–2023

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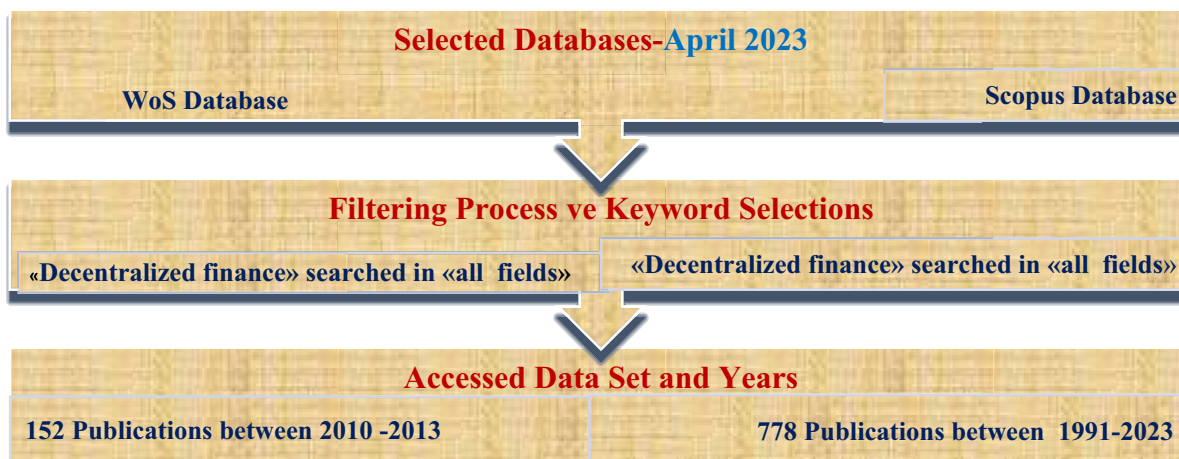


Fig. 1 Research method diagram

Table 2 Questions that constitute the content of the research

Question Number	Questions
1	"In which fields are the publications written, and what are the document types of these publications?"
2	"How many publications were produced each year?"
3	"Which countries prominently appear in the publication rankings?"
4	"Which countries receive the highest number of citations, and what kind of network exists among these highly cited countries?"
5	"What are the most frequently utilized keywords?"
6	"Who are the most frequently cited authors?"
7	"What are the most commonly cited references?"
8	"Which documents receive the highest number of citations?"
9	"Which organizations are noteworthy in terms of co-authored publications?"

database, we found that when the filtering numbers are the same, data congestion occurs due to the large amount of data in Scopus. In other words, the map the program created for Scopus was very superficial and shallow. However, when the filtering numbers were increased, we reached maps containing much clearer and richer data. Therefore, while analyzing the data in both databases, we entered different commands into the VOSviewer program, which gave us the best results.

Today, WoS and Scopus databases are considered by academic communities as the titans of bibliographic information. They also remain the most comprehensive databases for the last decade. Although WoS and Scopus databases have been compared by scientific authorities for nearly twenty years, it has not been decided which one is better [39]. For these reasons, we decided that the best databases to evaluate the research results on DeFi were WoS and Scopus, and we compared the findings we obtained from both databases with each other.

### Findings and assessment

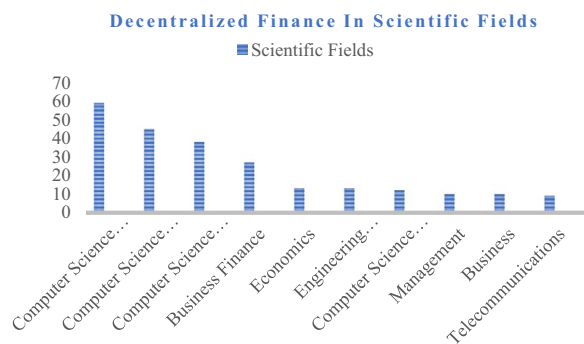
#### Question 1: "In which fields are the publications written, and what are the document types of these publications?"

In Table 3, the three primary disciplines exhibiting the highest publication count in the field of decentralized finance within the Web of Science database are as follows: Computer Science Information Systems, with 59 publications; Computer Science Theory Methods, with 45 publications; and Computer Science Interdisciplinary Applications, with 38 publications. Furthermore, the field of Business Finance accounts for 27 publications. Similarly, the foremost three scientific domains in the Scopus database are: Computer Science, Business, Management and Accounting, and Economics, Econometrics, and Finance. Upon reviewing Table 3, it is evident that the Scopus database encompasses a more extensive range of publications compared to WoS. These data are visually presented through Figs. 2 and 3.

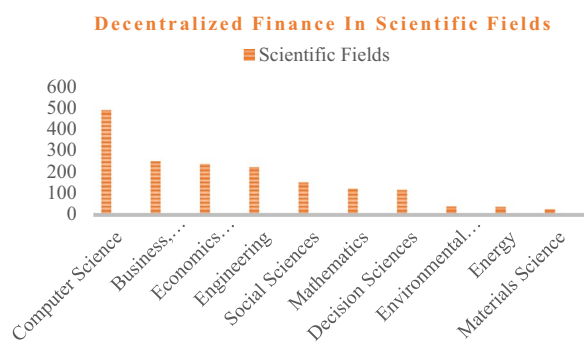
Figures 2 and 3 show the list of academic disciplines of DeFi publications. In parallel with these data, Table 4

**Table 3** Scientific disciplines of Web of Science and Scopus publications

Web of Science			Scopus		
No	Subject Area	Number	No	Subject Area	Number
1	Computer Science Information Systems	59	1	Computer Science	489
2	Computer Science Theory Methods	45	2	Business, Management and Accounting	251
3	Computer Science Interdisciplinary Applications	38	3	Economics Econometrics, and Finance	236
4	Business Finance	27	4	Engineering	223
5	Economics	13	5	Social Sciences	151
6	Engineering Electrical Electronic	13	6	Mathematics	122
7	Computer Science Software Engineering	12	7	Decision Sciences	116
8	Management	10	8	Environmental Science	38
9	Business	10	9	Energy	37
10	Telecommunications	9	10	Materials Science	26



**Fig. 2** Subject areas of Web of Science publications



**Fig. 3** Subject areas of Scopus publications

shows the list of document types of publications in academic disciplines.

Table 4 reveals that when publications are categorized based on document types, “Article” emerges as the predominant category in both databases. Notably, the Web of Science database comprises 84 articles, whereas the Scopus database features a higher count of 402 articles. Figure 4 offer a more in-depth visualization of this data.

**Table 4** Document types of Web of Science and Scopus publications

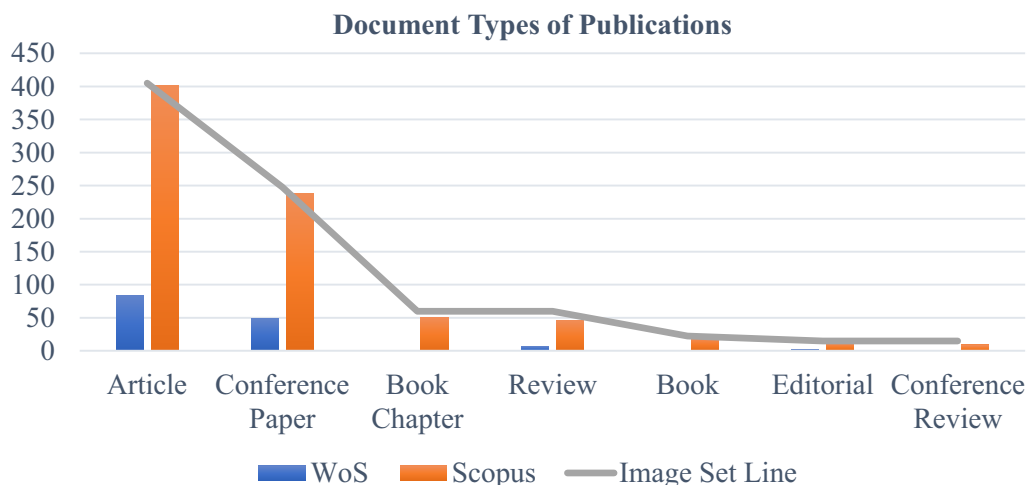
Web of Science			Scopus		
No	Area	Number	No	Area	Number
1	Article	84	1	Article	402
2	Proceeding Paper	49	2	Conference Paper	238
3	Early Access Articles	7	3	Book Chapter	51
4	Review	7	4	Review	46
5	Editorial	3	5	Book	20
6	Book Chapters	1	6	Editorial	12
7	Book	1	7	Conference Review	9

**Question 2: “How many publications were produced each year?”**

In recent studies from 2022 within the DeFi field, it is underlined that blockchain-based applications remain largely unexplored Eikmanns et al. [24]. The distribution of decentralized finance studies across different years, as presented in Table 5, reaffirms this observation. Worth noting is the fact that the initial publication within the WoS was in 2010, and the publications before 2020 were scarce (2019 (n=3), 2017 (n=1), 2016 (n=1), 2010 (n=1)). However, in the Scopus database, a substantial surge in publications is observed in the year 2022, totaling 394 publications. The noteworthy growth in the number of publications began in 2021 (n=146). Additionally, it is remarkable that the first publication within the Scopus database dates back to 1991. The number of publications increased from 146 in 2021 to 394 in the subsequent year.

Figure 5 illustrates the academic publications released in recent years within the WoS and Scopus databases. The upsurge in academic publications can be linked to the concurrent escalation in the value of cryptoassets. It is noteworthy that the global total market capitalization





**Fig. 4** Decentralized finance document types of Scopus and WoS publications

**Table 5** Comparison of publications published in WoS and Scopus

Web of Science Publishers		Scopus Publishers		Year		No. of Publications	
Year	No. of Publications	Year	No. of Publications	Year	No. of Publications	Year	No. of Publications
2023	23	2023	152	2014	3		
2022	83	2022	394	2013	1		
2021	31	2021	146	2010	3		
2020	10	2020	46	2008	1		
2019	3	2019	13	2006	2		
2017	1	2018	4	1991	1		
2016	1	2017	6	<b>Total</b>	<b>778</b>		
2010	1	2016	3				
<b>Total</b>	<b>152</b>	2015	2				

of cryptoassets commenced a substantial rise in late 2020 Yousaf et al. [51], Coin Market Cap [18].

**Question 3: “Which countries prominently appear in the publication rankings?”**

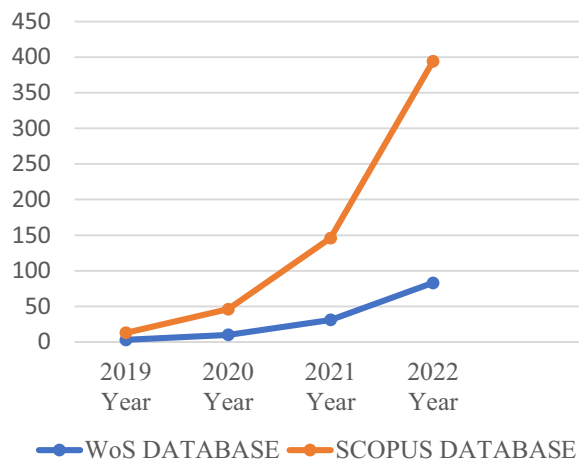
Figure 6 present the publications from the countries with the highest publication count. USA (WoS,  $n = 43$ ; Scopus,  $n = 176$ ) ranks first in both databases, followed by China (WoS,  $n = 22$ ; Scopus,  $n = 118$ ) and United Kingdom (WoS,  $n = 18$ ; Scopus,  $n = 102$ ), respectively.

**Question 4: “Which countries receive the highest number of citations, and what kind of network exists among these highly cited countries?”**

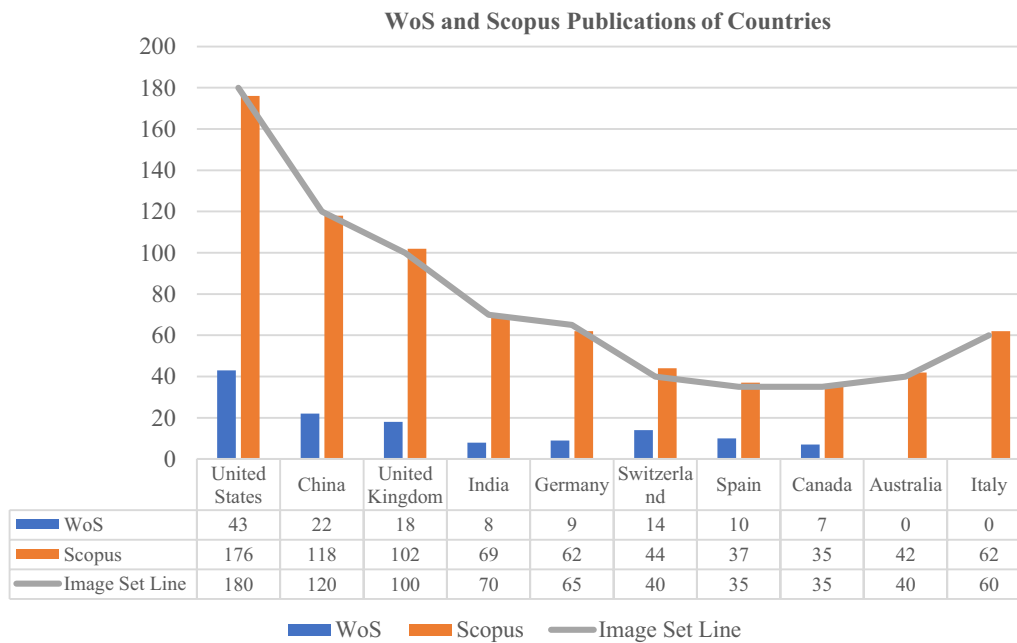
As a general judgment, it can be concluded that the most cited countries are the countries with the most publications on decentralized finance. Similarly, it can be assumed that the academic communities of the countries with the most publications are more advanced on the subject. When Table 6 is examined, it is clearly seen that there is an academic race between the USA and China regarding decentralized finance. In Figs. 7 and 8, it is seen that academic network connections are quite complex.

Table 6 shows which countries are cited most often. It is seen that the most cited countries in the databases are USA, China, and United Kingdom, respectively. In both databases, USA has more documents (Scopus,  $n = 173$ ; WoS,  $n = 37$ ), has cited more (Scopus,  $n = 1213$ ; WoS,  $n = 64$ ) and has more total links compared to other countries (Scopus,  $n = 218$ , WOS,  $n = 32$ ).

Figure 7 illustrates the network map of the most frequently cited countries in decentralized finance publications. The larger nodes denote the countries with the highest citation rates. Each color signifies the robust



**Fig. 5** Comparison of WoS and Scopus Publications



**Fig. 6** Top ten countries in decentralized finance on WoS and Scopus

**Table 6** From WoS and Scopus databases most cited countries and network links

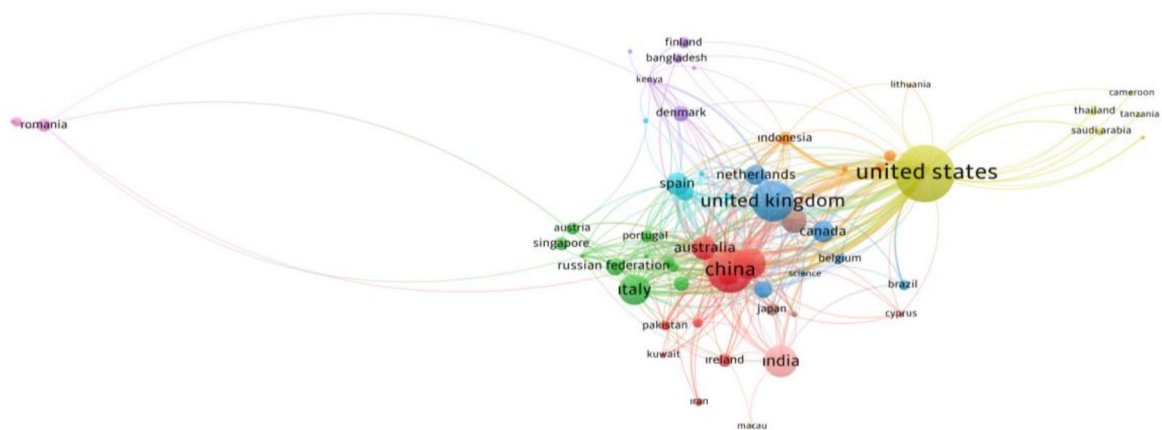
Web of Science					Scopus				
No	Country	No. Of Docs	Cit	Total Link Strength	No	Country	No. Of Docs	Cit	Total Link Strength
1	USA	37	64	32	1	USA	173	1213	218
2	China	18	94	38	2	China	115	574	85
3	England	17	131	74	3	United Kingdom	100	743	76
4	Switzerland	11	57	18	4	India	67	364	63
5	Ireland	9	17	8	5	Italy	61	249	91
6	Spain	8	21	21	6	Germany	60	419	173
7	Italy	7	39	22	7	Switzerland	42	201	35
8	Germany	6	45	22	8	Australia	40	431	132
9	Russia	6	10	17	9	Spain	37	147	49
10	Australia	5	50	28	10	Canada	35	141	43

network clusters formed among countries. Specifically, in the figure, the USA is clustered with Saudi Arabia, Thailand, and the United Kingdom; China forms clusters with the Netherlands, Belgium, Brazil, and France; India, Pakistan, Kuwait, Ireland, and Iran are associated with Italy; the Russian Federation clusters with Singapore, South Korea, Portugal, and Austria; and Romania is connected with Denmark and Finland.

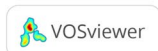
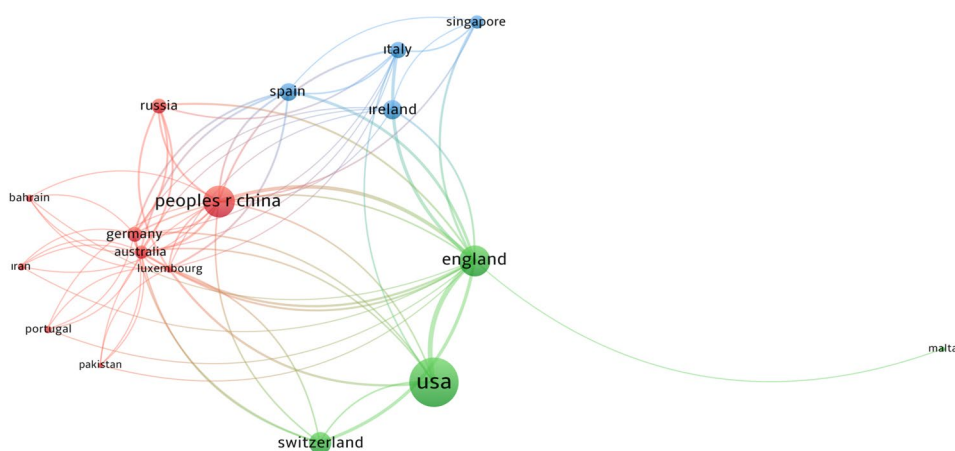
In recent years, there has been a surge in academic and professional publications originating from the USA and Europe. Within these publications, novel approaches to

mitigate DeFi risks have gained traction [15]. The European Union Commission adopted the digital finance strategy for cryptoassets in 2020. This strategy aims to facilitate the EU’s transition to the digital realm and enhance its adaptability to digitization (EU Communication, COM 591 Final).

Figure 7 was created using VOSviewer. The map is sourced from the Scopus database. The analysis type chosen was “Citation” with the analysis unit set to “countries.” Filtering was applied, and the map was generated using a minimum of one document and at



**Fig. 7** Top cited countries and network links in decentralized finance publications in the Scopus database



**Fig. 8** Top cited countries and network links in decentralized finance publications in the WoS database

least ten citations from each country. This map illustrates countries with the most extensive networks among each other.

Figure 8 demonstrates that the countries with the highest publication count in the field of decentralized finance are the USA, England, and China. Consequently, these countries possess the largest nodes in the diagram. Notably, the figure reveals that the countries can be divided into three distinct clusters. England, USA, Switzerland, and Malta are clustered together in green,

forming a robust network. China, Russia, Germany, Iran, and Pakistan have established another strong network, represented by the red cluster. Ireland, Spain, Singapore, and Italy are seen clustered in blue, constituting a separate network.

Figure 8 was created using VOSviewer. The map is derived from the WoS database. “Citation” was selected as the analysis type, and “countries” were chosen as the analysis unit. Countries were filtered using a minimum of one document and at least ten citation options, resulting



in the creation of a map. This map illustrates countries with the most extensive networks among each other.

**Question 5: “What are the most frequently utilized keywords?”**

The keywords created by the authors in Fig. 9 and WoS are displayed. The keywords corresponding to the largest nodes in the figure represent the most frequently used terms, namely: “decentralized finance,” “blockchain,” and “defi.” However, terms such as “smart contract,” “cryptocurrency,” “fintech,” “ethereum,” “bitcoin,” and “distributed ledger technology” are comparatively less utilized. Keywords shown in yellow denote terms that have recently started to gain usage. Among these terms are “metaverse,” “NFTs,” “investor attention,” “credit score,” “bubbles,” “peer-to-peer,” and “aquaculture.”

Figures 9 and 10 shown were preferred to be presented before the table. Because maps are pictorial representations of tables.

Figure 9 is created using VOSviewer. The map is sourced from the WoS database. “Co-occurrence” was selected as the analysis type, and “Author Keywords” were chosen as the analysis unit. The map was generated by applying a filter where each keyword was used at least once. The keywords produced by the authors are displayed on the map.

Figure 10 displays keywords generated by authors in publications related to decentralized finance within the

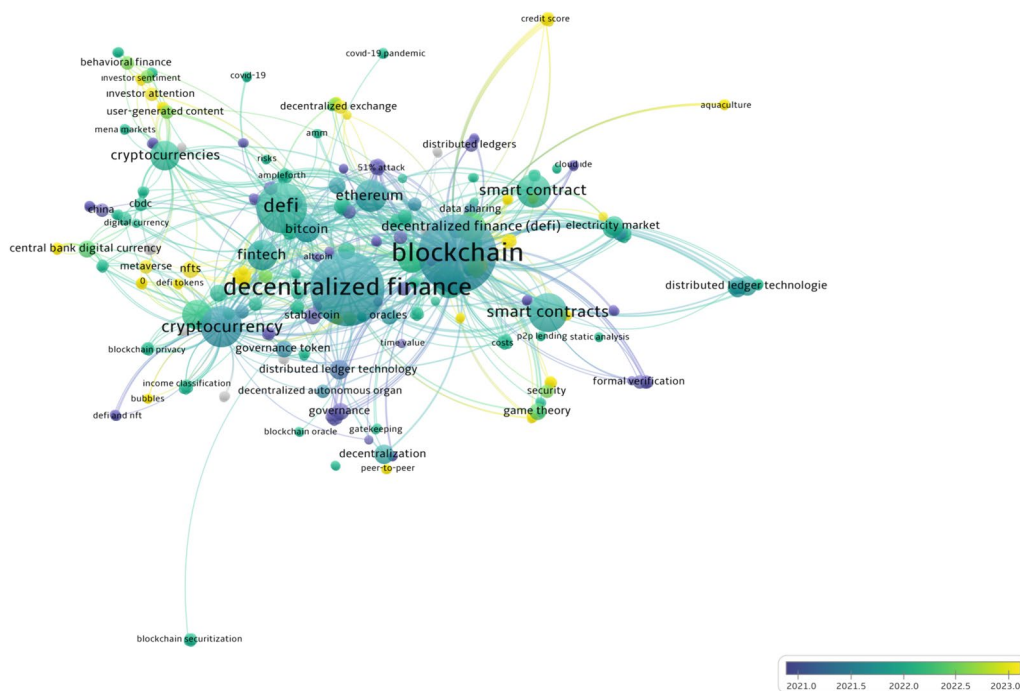
Scopus database. In the figure, the keyword “blockchain” is prominently positioned at the center, representing the largest node. While the “ethereum” node was formed in WoS, the “bitcoin” node emerged in Scopus. Presented in yellow are newly introduced keywords, including “web3.0,” “business model,” “AI,” “connectedness,” “fraud,” “token,” “DAO,” “non-fungible tokens,” “game theory consensus algorithm,” and “financial stability.” Keywords frequently used in both databases are “blockchain,” “decentralized finance,” and “defi,” respectively.

Figure 10 was generated using VOSviewer. The map originates from the Scopus database. “Co-occurrence” was selected as the analysis type, and “Author Keywords” were chosen as the analysis unit. The map was constructed by applying a filter that required a keyword to be used at least three times. The keywords commonly created by the authors are displayed on the map.

Frequently used keywords related to decentralized finance offer valuable insights for researchers interested in the field. These insights enable researchers to delve deeper into the subject matter. Table 7 provides numerical data concerning the frequency of occurrences and the total link width of keywords frequently generated by authors in both the WoS and Scopus databases.

**Question 6: “Who are the most frequently cited authors?”**

Table 8 provides a list of the top 10 most frequently cited authors. It is noteworthy that the author rankings



**Fig. 9** Featured keywords co-created by the authors in the WoS database



**Table 8** Top 10 co-cited authors (WoS vs. Scopus)

Web of Science				Scopus			
No	Author	Citations	Total Link Strength	No	Author	Citations	Total Link Strength
1	Nakamoto,S	54	494	1	Chen,Y	358	9941
2	Buterin,V	33	308	2	Gervais,A	301	13,100
3	Corbet, S	32	578	3	Nakamoto,S	270	6510
4	Schar,F	28	443	4	Bellavitis,C	253	5698
5	Gudgeon, I	24	430	5	Wang,Y	248	9723
6	Zetsche, Da	23	346	6	Zhang,Y	233	11,898
7	Wood, G	23	225	7	Zheng,Z	222	10,814
8	Zhou,I	21	345	8	Li,Y	212	9053
9	Qin, Kh	21	340	9	Wang,H	208	10,180
10	Chen,Y	21	332	10	Buterin,V	194	4971

differ between the two databases. For instance, Gervais, an author with a total link strength ( $n=13,100$ ) and cited ( $n=301$ ) times in Scopus, did not appear among the top ten authors in WoS. Another point of interest is that Scopus publications receive significantly more citations compared to WoS publications in the table. Nakamoto S stands out by being among the top three authors in both databases. In WoS, Nakamoto ( $n=54$ ) holds the first position among co-cited authors. Meanwhile, in the Scopus database, Chen Y ( $n=358$ ) ranks first in terms of common citations.

Figures 11 and 12 depict maps showcasing the most frequently cited authors. The top-cited authors in WoS are Nakamoto, S; Buterin, V; Corbet, S; Schar, F, and Gudgeon, I. In Scopus, the most cited authors are Chen, Y; Gervais, A; Nakamoto, S; Bellavitis, C, and Wang, Y. Each color visible on the maps signifies clusters among the authors. In the Scopus database, four author clusters are discernible in yellow, blue, red, and green, while five author clusters are evident in WoS. Nakamoto, S commands the most prominent node in both maps.

Figure 11 is created using VOSviewer. The map originates from the Scopus database. “Co-citation” was chosen as the analysis type, and “cited authors” were selected as the analysis unit. The map was generated by applying a filter that required an author to be cited at least fifty times. The most frequently cited authors are displayed on the map.

Figure 12 is created using VOSviewer. The map is derived from the WoS database. “Co-citation” was selected as the analysis type, and “Cited authors” were chosen as the analysis unit. The map was generated by applying a filter that required an author to be cited at least five times. The most frequently cited authors are displayed on the map.

#### Question 7: “What are the most co-cited references?”

Figures 13 and 14 depict the most frequently cited references. The references most commonly cited, represented by the largest nodes in WoS, are as follows: Schar [43], Nakamoto [35], and Wood [49]. In Scopus, these references are Chen and Bellavitis [16, 17], Zheng et al. [53], Nakamoto [35], and Fisch and Momtaz [25]. References commonly cited in both databases include Nakamoto [35] and Wood [49]. On the maps, clusters denoted by yellow, green, red, and blue represent networks among references.

Figure 13 is created using VOSviewer. The map is sourced from the WoS database. “Co-citation” has been selected as the analysis type, and “Cited references” are chosen as the analysis unit. The map was generated by specifying a minimum of three citations from a cited reference source. The most frequently cited references are displayed on the map.

Figure 14 is created using VOSviewer. The map originates from the Scopus database. “Co-citation” has been chosen as the analysis type, and “Cited references” are selected as the analysis unit. The map was generated by choosing a minimum of five citations from a cited reference source. The most frequently cited references are displayed on the map.

#### Question 8: “Which documents receive the highest number of citations?”

In Figs. 15 and 16, the density maps of the most frequently cited documents are presented. Documents with a more intense yellow color on the maps indicate the most cited documents. In the Scopus database, the most cited documents include, Schär [43], Deepa et al. [20], Deng et al. [21], Yousaf et al. [51], Zetsche et al. [52], and Chen and Bellavitis [17]. In the WoS database, the most

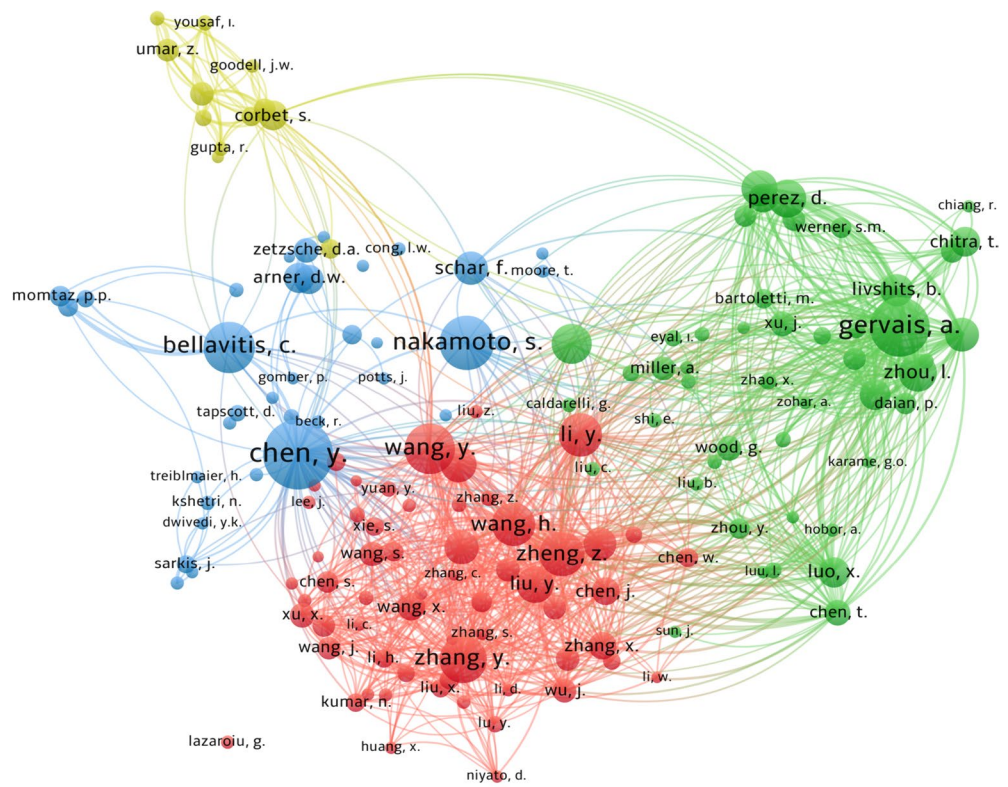


Fig. 11 Highlights from co-cited authors in the Scopus database

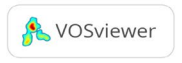
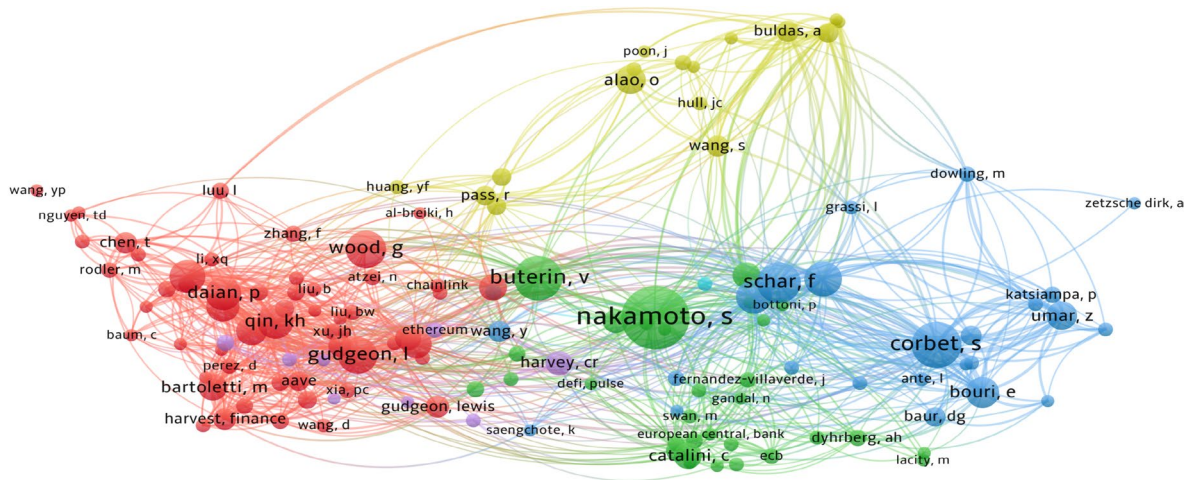
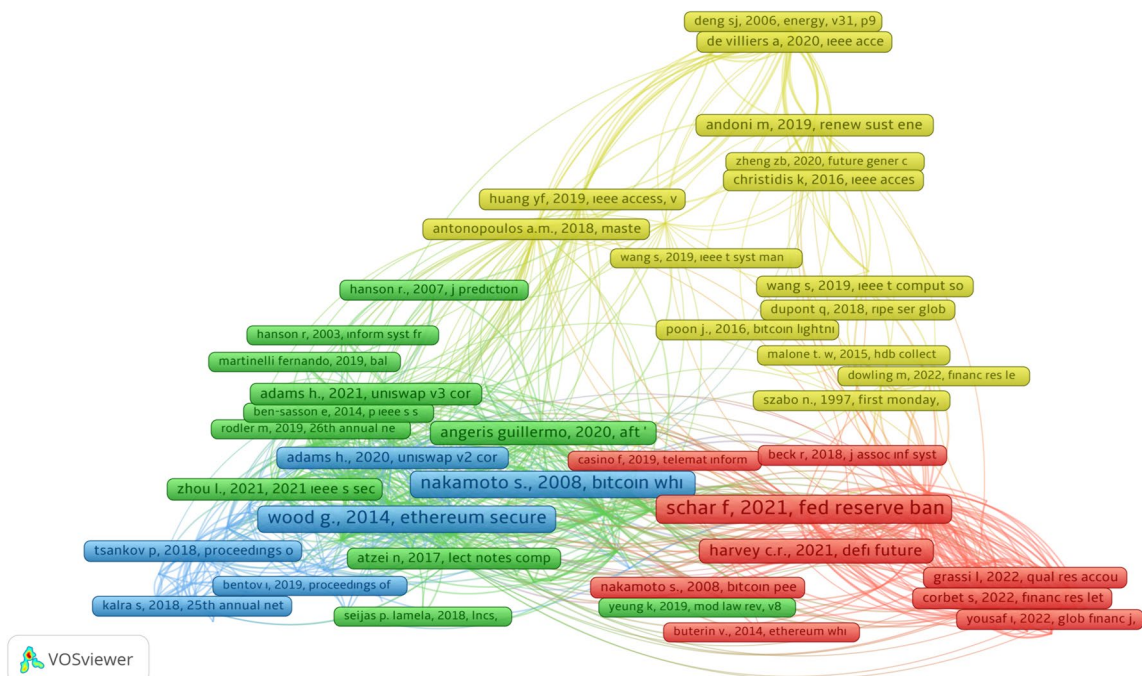
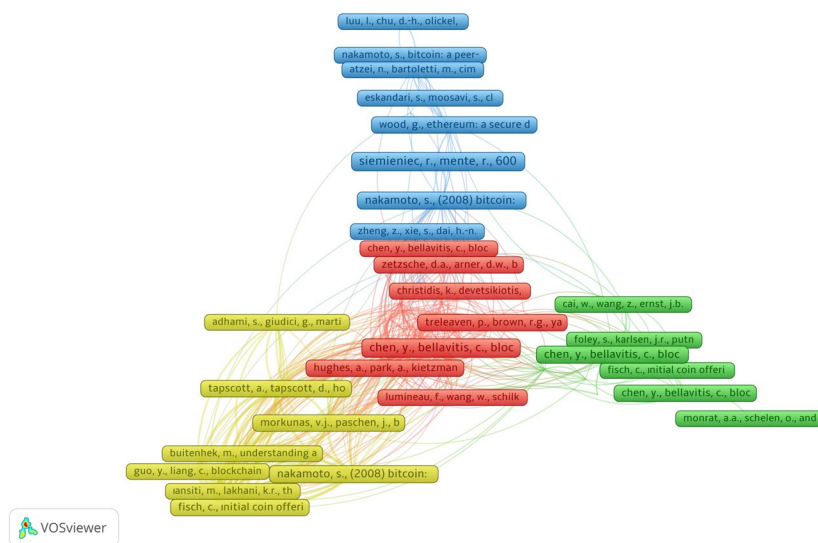


Fig. 12 Highlights from co-cited authors in the WoS database





**Fig. 13** Most commonly cited references in WoS database



**Fig. 14** Most commonly cited references in Scopus database

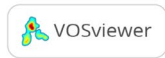
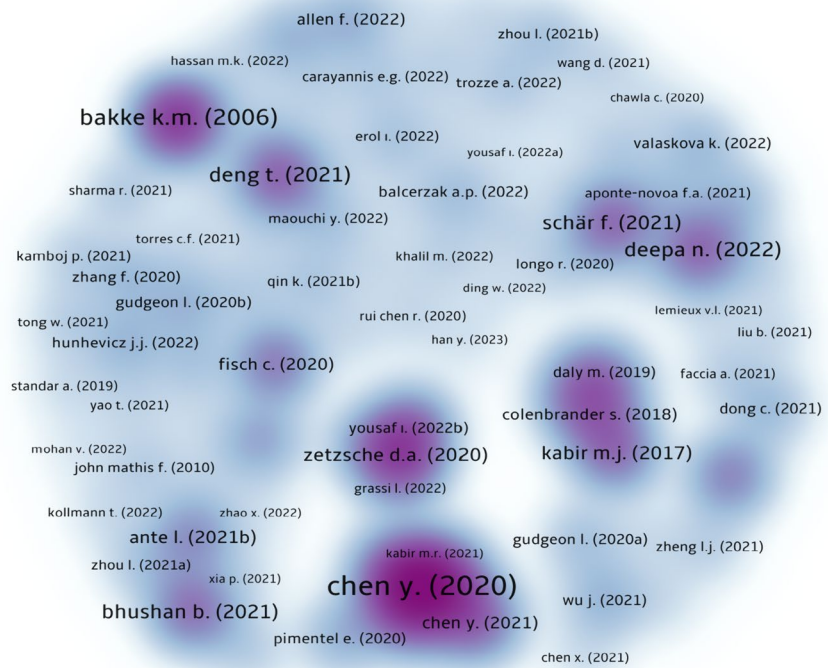
cited documents appear to be Zetszche et al. [52], Schär [43], Allen et al. [4], Qin et al. [41, 42], Gudgeon et al. [28, 29], and Bamakan et al. [10].

Figure 15 is created using VOSviewer. The map originates from the Scopus database. “Citation” has been chosen as the analysis type, and “Documents” are selected as the analysis unit. The map was generated by

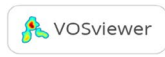
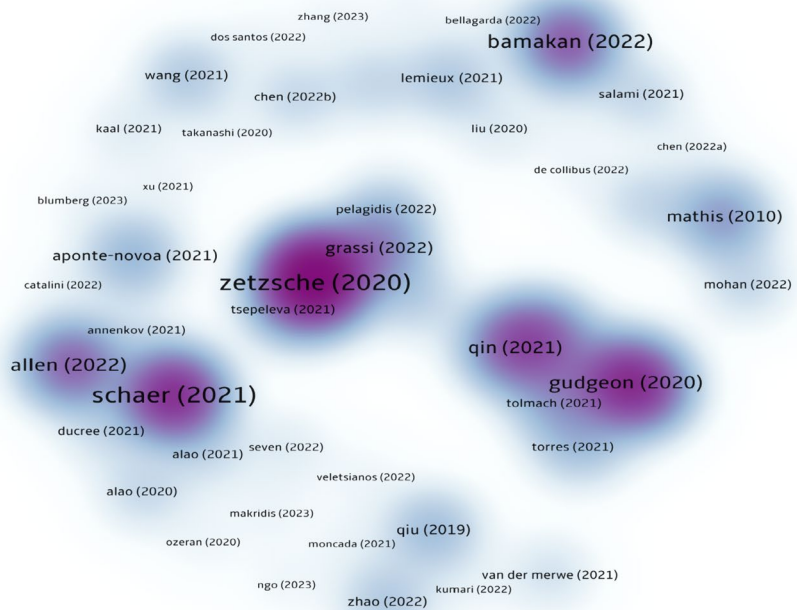
applying a filter that required a document to be cited at least ten times. The density of the most frequently cited documents is illustrated on the map, with documents appearing in yellow color representing those with higher citation counts.

Figure 16 is created using VOSviewer and belongs to the WoS database. “Citation” has been selected as





**Fig. 15** Most cited documents in Scopus database



**Fig. 16** Most cited documents in WoS database

the analysis type, and “Documents” are chosen as the analysis unit. The map was generated by applying a filter that required a document to be cited at least once. The density of the most frequently cited documents is visualized on the map, where documents colored in yellow indicate higher citation frequencies.

Table 9 provides a comparison of the most cited documents in the databases along with the number of citations for each document. In WoS, Schär [43] stands as the top document with 43 citations. In Scopus, Chen and Bellavitis [17] holds the first position with 202 citations. The table also presents the authors’ most cited publications and brief summaries of these publications.

**Question 9: “Which organizations are noteworthy in terms of co-authored publications?”**

Figures 17 and 18 depict the standout organizations in co-authored publications. Figure 17 illustrates that 17 organizations within the Scopus database have established a robust and extensive collaborative network. In Fig. 18, which represents Web of Science, we can observe the formation of two distinct clusters among these organizations. Specifically, the organizations Australian Research Council, Centre for Finance Technology Entrepreneurship, University of Hong Kong, and UNSW Sydney have clustered together, forming a network highlighted in red. Meanwhile, the organizations University of Oslo, University of Luxembourg, and Heinrich Heine University have formed another network, indicated by the color green.

Figure 17 is created using VOSviewer and is based on the Scopus database. The analysis type chosen for this map was “Co-authorship,” and the analysis unit was set to “organizations.” To generate this map, we applied a filter to include organizations with at least one document and a minimum of ten citation options. The map displays the organizations with the most extensive networks.

Figure 18 is generated using VOSviewer. The map is based on the Web of Science database. “Co-authorship” was chosen as the analysis type, and “organizations” was selected as the analysis unit. The map was generated by applying filters, requiring at least one document associated with an organization and at least five citation options. The map displays organizations with the most extensive networks.

In Table 10, we compare the most cited organizations and the number of citations they have received. Imperial College London ranks first with 6 documents and 76 citations in WoS, while the School of Stevens Business at the Institute of Technology ranks first with 2 documents and 203 citations in Scopus.

## Discussion

### General evaluation

Policy makers fail when they cannot fully identify fundamental economic problems and produce the necessary solutions. Individuals who are financially weakened due to this failure will try to improve their deteriorated financial situation by experimenting with different investment instruments. This effort is explained in economics by the concept of “homo economicus.” The concept of homo economicus in its simplest terms refers to individuals aiming for the highest benefit with their economic activities and behaviors. It should not go unnoticed that Bitcoin’s emergence occurred right after the 2008 economic crisis. Often, during periods of economic crises and global economic contractions, individuals try to compensate for their lost financial well-being by experimenting with different investment instruments. Similarly, during the global economic contraction caused by the Covid-19 pandemic, it has been observed that individuals’ demand for cryptocurrencies has increased.

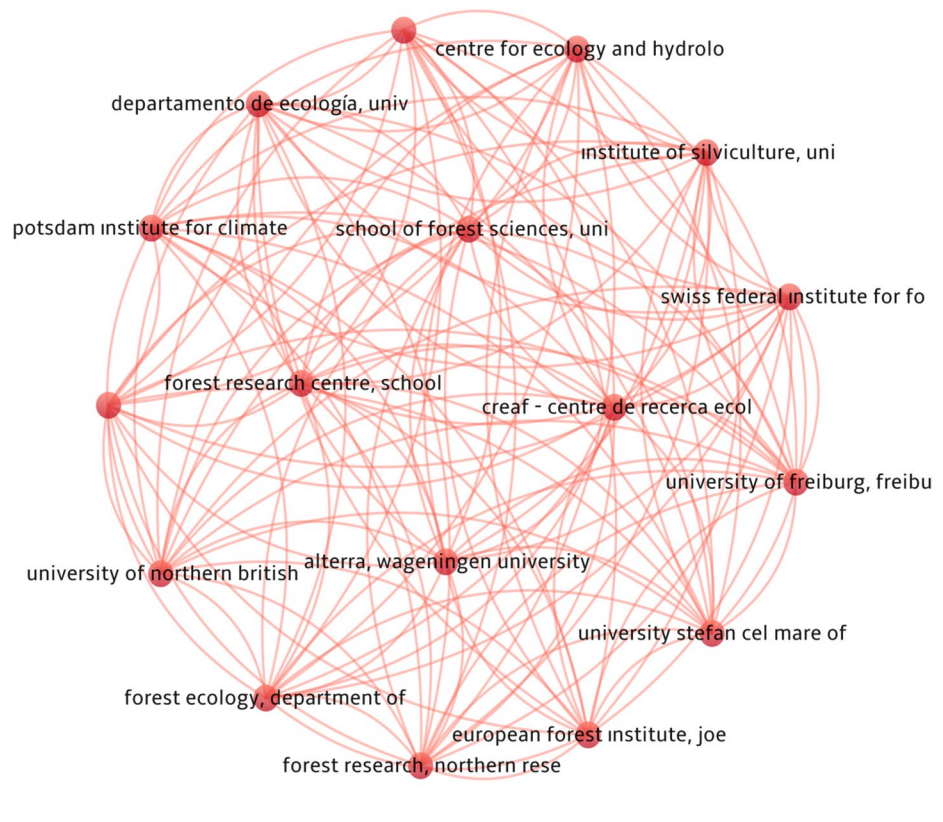
It is very important to manage monetary and fiscal policies correctly in times of struggle with both global and national economic crises. However, with properly managed monetary and fiscal policies, macroeconomic indicators will improve, and individuals’ financial welfare levels will increase. When the right policies are not implemented, poverty occurs in societies, and income inequality increases. It is at this point that individuals explore different financial assets that they have not experienced before to compensate for their lost wealth. Chief among these experiences are investments in digital assets. The reason why the interest in digital assets is much higher in developing countries than in developed countries is mostly related to the economic development and development levels of the countries. The interest of citizens in digital assets varies depending on the macroeconomic indicators of each country. However, financial literacy is one of the most important parameters that determine individuals’ interest in digital assets. The fact that individuals’ savings are losing value due to the strategies implemented by policymakers makes individuals more enthusiastic about investing in digital assets that cannot be influenced by any policymakers.

Digital assets are based on blockchain technologies. Blockchain technologies are developing at an unpredictable pace. This high rate of development brings with it some problems. At this point, one of the most significant problems is that cybersecurity systems that protect digital platforms cannot keep up with the speed of blockchain technologies. Living in smart homes and smart cities that require high technology is comfortable and fun. But the complexity of the security systems of these homes

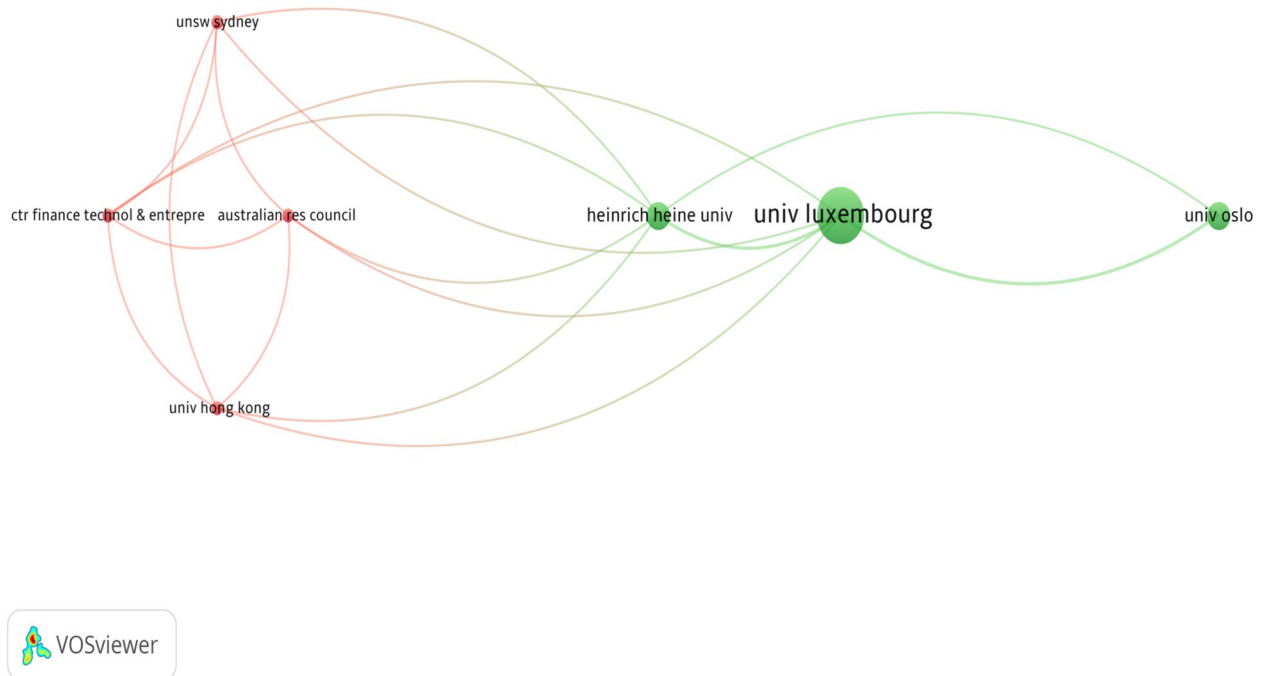


**Table 9** (continued)

Web of Science		Scopus	
No	Document	Summary of the Article	Citations
No	Document	Summary of the Article	Citations
7	Qin et al. [41, 42] "An empirical study of defi liquidations: Incentives, risks, and instabilities"	The article is the first study to examine the credit-debt relationship of the Ethereum DeFi ecosystem. The research measured liquidation data of cryptocurrencies that make up more than 85% of the lending market on Ethereum.	20
			7
			77
		The article explains that decentralized finance will undermine the effectiveness of traditional financial regulations. It also discusses the concepts of FinTech ("financial technology") and RegTech ("regulatory technology").	
8	Caldarelli and Ellul [15] "The blockchain oracle problem in decentralized finance—a multivocal approach"	In the article, researchers discussed the oracle problem. Researchers have explored ways to overcome this problem, known as the "prophecy problem".	19
			8
			75
		The article argues that the development of the decentralized finance ecosystem poses the risk of financial collapse. The authors investigate the effects of price fluctuations and weaknesses in the design of blockchain-based smart contracts on the DeFi crisis.	
9	Mathis and Cavinato [32] "Financing the global supply chain: growing need for management action"	The article briefly argues that decentralized finance functions cause financial inefficiencies. According to the authors, finance discipline should be renewed according to changing needs at every step of the supply chain.	13
			9
			63
		The study aims to integrate blockchain into these systems using the halal traceability strategy. The sample of the research consists of 143 Malaysian halal food and beverage businesses.	
10	Grassi et al. [27] "Do we still need financial intermediation? The case of decentralized finance—DeFi"	The article evaluates the interaction processes between humans and algorithms. According to the authors, DeFi has inherited risks that facilitate illegal behavior.	12
			10
			62
		The article presents a bibliometric analysis of 468 peer-reviewed articles examining smart contracts. In addition, a general evaluation was made by examining the references of these articles.	



**Fig. 17** Organizations featured in co-authored publications in the Scopus database



**Fig. 18** Organizations featured in co-authored publications in the WoS database



**Table 10** Top 10 most cited organizations (WoS vs. Scopus)

Web of Science				Scopus			
No	Organization	No. of Docs.	Cits.	No	Organization	No. of Docs.	Cits.
1	Imperial College London	6	76	1	Stevens Institute of Technology	2	203
2	University of Luxembourg	4	53	2	The University of Auckland	1	202
3	University of Basel	1	44	3	University of Washington	1	123
4	Heinrich-Heine-Universität Düsseldorf	2	43	4	Tsinghua University	1	101
5	Australian Research Council	1	43	5	University of California, Berkeley	1	101
6	Ctr Finance Technol & Entrepreneurship	1	43	6	Durham University	1	96
7	Univ Hong Hong	1	43	7	Korean Southeast Center For the 4th industrial Revolution Education	1	96
8	Unsw Sydney	1	43	8	School of Engineering Deakin University	1	96
9	Chinese Academy of Sciences	1	26	9	Vellore Institute of Technology	1	96
10	Huawei Cloud Techcoitd	1	26	10	University of Basel	2	95

can overshadow the comfort of the homes. The same problem applies to blockchain technologies on which decentralized finance is based. While traditional economies are being replaced by digital economies, all rights and services such as property rights, patented inventions, financial services, education and health services, elections, and voting systems are at the turning point of technological transformation. For all these reasons, it is observed that academic studies are increasing rapidly in areas related to technological transformation to quickly adapt to technological changes. The deficiencies in the legal and technological infrastructure on which blockchain technologies are based are being addressed with the guidance of these studies. Otherwise, it is inevitable that decentralized finance applications, which offer great opportunities, will create crises due to security vulnerabilities and inadequate legislation.

#### Controversial main conclusions of the findings

This research, in which a bibliometric comparative analysis of WoS and Scopus databases was conducted, found that the decentralized finance (DeFi) literature started to expand especially in 2020. This year when the Covid-19 pandemic started and the global economic contraction occurred. It is known that investors' demands for cryptocurrencies increased during this period. This demand has not gone unnoticed by academic communities. Researchers have started to produce more publications about DeFi.

#### Contextual approach to debate

When the interdisciplinary fields of publications are examined in this research, it is seen that computer science comes to the fore. DeFi is initially a technical subject involving computer science because the basic principles

of cryptoassets and blockchain technologies are based on open-source software. But blockchain is the technology that will change the future and trigger all financial, economic and social events in the future. Blockchain technologies are the technologies that will determine the prosperity of nations and the direction of international relations in the future. For these reasons, there are countless topics in the DeFi literature that social scientists can advance. Respectively, basic research topics such as the psychology of financial behavior, management of blockchain platform businesses, digital law, digital economy, the effects of cryptoassets on trade, the effects of cryptoassets on financial systems, and the future of DeFi protocols are open to development. The future of cryptoassets will undoubtedly be bright in parallel with advancing technology when the necessary regulations are made in international law. However, the most fundamental problems will arise from the failure of security and legal regulations to keep up with the speed of technology.

#### Limitations of the study

This bibliometric research exclusively focuses on academic studies published in the WoS and Scopus databases. Other databases were not considered and are not included in this study. Therefore, future bibliometric studies should incorporate data from different databases for a more comprehensive analysis.

Another limitation of this research is that it filtered only with "decentralized finance" as a keyword. In a bibliometric analysis investigating the dark side of cryptocurrencies, keywords such as "crime," "ponzi," "scam," and "fraud" were used [14]. Similarly, new research topics can be discovered by using different keywords. Another limitation of the research is that we could not give the same commands to the VOSviewer

program because the Scopus database was much larger than WoS. The fact that the number of Scopus publications is five times higher than WoS publications is a limitation in comparative bibliometric analysis.

In addition, because we used the “All Fields” filter on the databases, three articles that were not related to the subject were displayed in maps and publications (See; Bakke and Wibbels [9], Kabir et al. [33] and [19]).

## Conclusion

### General evaluation

In this study, we conducted a bibliometric analysis of decentralized finance (DeFi), which is based on blockchain technologies. Using the Scopus database, we analyzed 778 publications spanning the years 1991 to 2023. Additionally, we examined 152 publications from 2010 to 2023 in the Web of Science (WoS) database using various bibliometric analyses. The results reveal that Scopus contains a significantly larger number of publications compared to WoS. While both databases share similarities, they present distinct statistical data. This article offers researchers a comprehensive bibliometric analysis covering a total of 930 publications. We analyzed and interpreted the data using the VOSviewer program, presenting the results through maps, statistical tables, and figures. The bibliometric analysis addresses a total of 9 key questions and provides answers to these questions.

### Main results of the research

According to the results of the research, the countries with the most publications in DeFi literature are the USA, China, and the UK, respectively. In both WoS and Scopus, the USA and China share the first two places. Therefore, the USA and China are quite competitive in the DeFi literature. In addition, it has been determined that European Union member countries such as Germany, Italy, and Spain are relatively behind in DeFi publications. The most cited author in Scopus is Chen, Y, and in WoS, Nakamoto, S. In the literature, computer science publications mostly stand out. In DeFi publications, it has been determined that the Scopus database is quite rich in content compared to the WoS database. In DeFi publications, the Scopus database is on average five times richer than the WoS database in computer science, finance, business and management publications.

In addition to all the information conveyed, it was determined that social science publications in the DeFi literature were left behind compared to publications written in the fields of computer science, finance, business and management. The summary of the interdisciplinary view of DeFi literature is explained with the iceberg

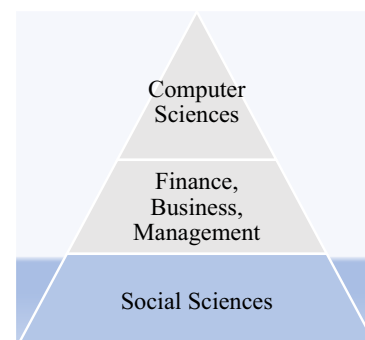
example shown in Fig. 19. The top of the iceberg is represented by computer science publications that have the most publications in the DeFi literature and are highly visible. Finance, business and management publications represent the second layer of the iceberg. There are relatively fewer publications in the field of social sciences. This is why the social science discipline, which has not yet been fully explored, represents the bottom of the iceberg in DeFi literature.

### The importance of the research and its contribution to the field

Decentralized finance is one of the topics that has remained current in recent years. This research measures how much academic literature has contributed to decentralized finance, which has remained up-to-date in recent years. Research in which this contribution is measured with numerical data is called bibliometric analysis. Bibliometric analyses draw a general framework about the subject under investigation. Researchers can explore unique areas of study by starting from the general framework created in this research. They will also be able to easily identify gaps in the literature.

### Comparison of WoS and Scopus statistical results: similarities and differences

According to the results obtained in this research, WoS and Scopus publications exhibit both similarities and differences. Publications related to DeFi in both databases began to increase in 2021; however, the most noticeable difference emerges in 2022. It was determined that the number of publications increased by an average of 270% in 2022 compared to 2021, reaching its peak (2021, WoS: 31, Scopus: 146); (Year 2022, WoS: 83, Scopus: 394). Computer science ranks first in publication rankings in both databases. Additionally, Scopus appears to be significantly richer than the WoS database in publications covering social



**Fig. 19** Interdisciplinary view of decentralized finance in WoS and Scopus databases

sciences such as finance, economics, management, and business (Computer Science, WoS: 154, Scopus: 489); (Finance, Business, Economics, Finance; WoS: 60, Scopus: 487).

In both databases, articles rank first in terms of the number of publications, while conference papers and proceedings are ranked second. The most cited countries in DeFi publications are the USA and China, respectively. Among the top ten countries in the ranking, the UK and EU member countries like Germany, Spain, Sweden, and Italy also feature. Notably, India is among the top ten countries in both databases for DeFi publications. While Russia made it to the top ten in the WoS rankings, it did not appear among the top ten in Scopus.

When examining the networks between countries, in the WoS database, it has been observed that China has formed a strong network by clustering with Russia and Germany, while the USA has formed a strong network by clustering with the UK. Additionally, bibliometric maps show that Italy, Ireland, Singapore, and Spain cluster together to form another strong network. Networks between countries appear larger and more complex in Scopus.

The first five keywords most frequently co-created by authors are similar in both databases, including “Blockchain,” “Decentralized Finance,” “DeFi,” “Cryptocurrency,” and “Smart Contracts.” However, differentiation was observed in the top twenty keywords. Notably, the keywords “NFTs,” “Regulation,” “Uniswap,” and “Electricity Market” are not among the top twenty in Scopus, although they are ranked in the top twenty in WoS. Conversely, keywords like “Metaverse,” “Central Bank Digital Currency,” “Security,” “Artificial Machine Learning,” and “Solidity” are among the top keywords in Scopus but not in WOS.

The most frequently cited author in both databases is Nakamoto S. In WoS, Nakamoto S, (n: 54) holds the top position in citations, while in Scopus, Chen Y (n: 358) ranks first in citations. In WoS, Buterin V (n: 33) ranks second in citations, and Corbet, S (n: 32) ranks third in citations. In Scopus, Gervais A (n: 301) ranks second in citations, and Nakamoto S (n: 270) ranks third in citations.

Among the most cited documents in WoS, Schär [43] has 43 citations and Chen and Bellavitis [17]. ranks first with 202 citations in Scopus. Regarding the most cited organizations in co-authored publications, in WoS, Imperial College London ranks first with 6 documents and 76 citations, while in Scopus, the School of Business at Stevens Institute of Technology stands out with 2 documents and 203 citations.

### The results obtained in similar studies in the literature

According to the research findings, computer science publications occupy the top spot among the prominent branches of science in DeFi publications. Aysan et al. [8] conducted a bibliometric analysis of bitcoin articles and discovered that 33% of the total publications were led by computer science. This study reveals a rapid increase in DeFi publications since 2021. The swift surge in DeFi publications can be directly attributed to the growing number of investors investing in blockchain-based projects. Stepanova and Eriņš [45] confirmed this trend by examining DeFi applications using 34-month indicators, demonstrating that DeFi users are increasing despite the risks in blockchain-based financial markets. Wronka [50] underscores the belief among researchers that DeFi applications may integrate into the existing banking system in the future, emphasizing the importance of carefully considering all risks in the DeFi industry.

Caldarelli and Ellul [15] highlighted that more than \$15 billion was invested in DeFi projects in 2020 alone. Another notable finding in this study is that the USA, the United Kingdom, and China are the leading countries in DeFi publications, a trend supported by the research of Patel, Migliavacca, and Oriani [37]. Some of the prominent keywords in the bibliometric analysis include “blockchain,” “decentralized finance,” “DeFi,” “smart contracts,” “cryptocurrency,” “security,” “Ethereum,” and “Bitcoin.” Guo et al. [30] findings in their bibliometric analysis of blockchain studies corroborate the data obtained in this study.

### Suggestions to researchers and future directions

Significant efforts are required to enhance the security of blockchain technologies, particularly in the realm of smart contracts. Smart contracts have the potential to prevent financial losses and abuses, underscoring the need for further research in this area. Additionally, there is a need for legal studies addressing the production, purchase, sale, use, and characteristics of NFTs.

If researchers want to conduct a bibliometric research, they can turn to different databases. For example; Bibliometric analysis of postgraduate theses written in the field of blockchain will be very useful for researchers. In a bibliometric study examining postgraduate theses in the field of blockchain, it was revealed that doctoral theses were insufficient [22]. A study examining the content analysis of doctoral theses written in the field of Blockchain would be very useful for the literature.

Academic research on the Metaverse remains limited. Specifically, more research is needed to explore the financial innovations that Metaverse applications may introduce and to find solutions to the challenges they may

present. Moreover, cryptocurrencies are excellent tools for laundering money. That is why internationally binding agreements are needed. This issue is at a level that can affect international relations. That is why researchers whose field of expertise is international relations have important duties. Additionally, cryptomining, fraud in digital currency markets, and crypto-cybersecurity awareness issues will remain current.

Another issue that particularly draws our attention is Oracles. DeFi platforms use oracles to retrieve asset data from the outside world. However, end users are unaware of these software and devices. Investors' funds are endangered by mismanagement of Oracles. There is an Oracles problem in decentralized finance. However, there are a very limited number of studies on the subject.

Research on the amount of energy spent in the production of cryptocurrencies and alternative uses of this energy will be very valuable. Bitcoin mining is known to consume huge levels of energy. How much energy is spent on the production of cryptocurrencies? Where can this energy be used alternatively? There is a need for articles that seek answers to these questions. Publications in the literature are mostly studies on the financial risks caused by DeFi. More studies are needed on the impact of cryptocurrencies on international trade.

Explaining BeFi theories about DeFi pricing is a subject that is still developing in the literature. Therefore, there are gaps in the literature regarding the conceptualization of BeFi and behavioral psychology in the field of DeFi. For example, what factors affect investors' psychological security perceptions and financial security perceptions underlying their adoption of cryptoassets as an investment tool? How do our social networks influence our demand for cryptoassets? How do cryptoassets price our behavior on social networks? In addition, there is a need for qualified studies on the responsibilities of blockchain platform operators and the following questions should be answered; what should be the legal and financial responsibilities of blockchain platform businesses? How do these platforms differ among themselves? Moreover, DeFi should be evaluated separately on a micro and macro level. From this perspective, the research questions that need to be asked are as follows: Do households' income levels affect their demand for cryptoassets? Does the demand for cryptoassets differ in developed and developing countries? The answers to most of these questions are the research area of social sciences. Therefore, there is a large body of the DeFi iceberg that has not yet been discovered.

#### Abbreviations

DeFi	Decentralized finance
NFT	It is "non-fungible token."The term "non-fungible token" refers to unique and non-fungible token assets

Blockchain	It is a type of ledger in which data are digitally encrypted and stored in blocks linked to each other like a chain in chronological order
Oracle	Third-party software or devices that enable blockchain and smart contracts to interact with data outside the network are called oracles
BRICS	It is used to refer to the economies of Brazil, Russia, India, China and South Africa
BeFi	It is behavioral finance theory. It investigates the effects of psychological effects on the pricing of financial assets

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#### Disclaimer

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of any affiliated agency of the authors.

#### Author contributions

GA analyzed and interpreted the data with the VOSviewer program. She contributed to the methodology, data improvement, and preparation of visuals in the research. She made significant contributions to the formal analysis, conceptualization, and writing of the original text. HAO managed and supervised the project. He contributed to the methodology, formal analysis, conceptualization, and visualization. He made a significant contribution to the review, editing, supervision, interpretation, and writing of the original text. All authors read and approved the final manuscript.

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