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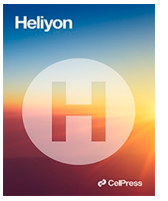

Research article

The rise in popularity of central bank digital currencies. A systematic review

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ABSTRACT

Central bank digital currencies (CBDCs) have been growing in popularity since 2018, as worldwide countries explore their impact and implementation options. This article analyzes the state of research around central bank digital currencies and the evolving landscape of CBDCs, and explores emerging areas of research and trends by using the PRISMA method and VOSviewer, with the goal of showing the main opportunities and challenges related to them. AMSTAR, DistillerSR, Eppi-Reviewer, ROBIS, and SRDR were the screening and quality evaluation tools employed for study eligibility criteria, design screening and content selection, text analysis data extraction, methodological quality predictors, and reliable and reproducible evidence assessment. A total of 1024 articles on central bank digital currencies were identified in Scopus and the Web of Science, out of which 747 have been included in the review (documents which were not in English language and not categorized as journal articles were excluded). Through an analysis of the relevant literature, the study categorizes CBDC research into positive, negative and neutral research, with a particular focus on sustainability issues, and conducts a keyword co-occurrence analysis using VOSviewer, following a narrowing down of the relevant articles to be included in the study by applying the PRISMA framework. This generates an overall view for experts and researchers who can use the main analyzed features of CBDCs and adapt them accordingly, taking into account relevant macroeconomic characteristics. The study highlights the need to continue interdisciplinary research, by adapting the research and CBDC characteristics to keep up with the latest technologies and with the shift towards green finance, and explores the elaborate relationship between finance, technology and sustainability.

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1. Introduction

Monetary policy can be defined as the process through which a central bank, currency board, or competent state institution puts into place a plan of action in order to determine the evolution and impact of crucial factors on the economic activity of the country. Amongst others, management supply and interest rates play a key role, both used to reach macroeconomic aims such as maintaining the inflation rate, consumption, Table 7. 2020–2022 evolution of CBDC research. Authors' own presentation.

liquidity and growth [1–3]. Through the regulation of foreign exchange rates, the sales and purchases executed by government banks, and changes in interest rates, these aims can be achieved [1]. Decisions with regard to the aforementioned monetary market factors are made within monetary policy meetings, which affect the overall economy and industry sectors and markets. One must stress the difference between the concepts of fiscal and monetary policy. In fact, fiscal policy should be seen as the borrowing, consumption, and spending of individual people and businesses rather than government borrowing and spending, as is the case with monetary policy [1,3]. When it comes to monetary policy, central banks put the focus on money supply and interest rates. Institutions such as the European Central Bank, the Bank of England, the Reserve Bank of Australia, the US Federal Bank, or the Bank of Japan use monetary policy as a means through which they stabilize the currency of their region or country, stimulate the economy, and control inflation. In other words, central banks have a certain amount of power over how much money costs, which in exchange can influence the amount of money spent by businesses and people [1,4,5].

Whether central banks adhere to a rigorous policy or to a more permissive one [6], their main goal remains ensuring low inflation with the intention of maximizing wealth for society [7,8]. Under this framework, it is stated that everyone is impacted by inflation, especially those with low incomes, which is used as an argument by central banks to defend their actions in fighting against inflation via monetary policy tools. Standard monetary policy encompasses gradual interest rate changes with the purpose of reaching an optimal, specified interest rate and stable inflation [9]. Similar to traditional money, central banks can create and supply digital currencies for use in payment transactions. These do not physically exist and are part of the transition from a cash- or offline-based society, as more and more people use their credit and debit cards to make cashless or virtual payments [10]. Several central banks are considering the issuance of digital currencies, for example, out of resource consideration. Some of the institutions are the People's Bank of China (digital yuan), the Central Bank of Uruguay (e-peso), and the Sveriges Riksbank (e-krona), while others (such as the European Central Bank, the Federal Reserve, or the Bank of England) are researching the implications of doing so [11–14].

Research about digital currencies and their effects is growing [11,15], and covers a wide range of topics, including central bank digital currencies (CBDCs), associated risks with the usage of digital currencies, the general and specific application of digital currencies, public opinion regarding digital currencies, risks regarding cybersecurity, privacy, data encryption, etc. Both central banks and policymakers investigate the different aspects of central bank digital currencies, as part of the emerging blockchain technologies and artificial intelligence-driven developments that now shape the banking and fintech landscape, as well as the customer experiences and the numeric transition that is taking place worldwide [14,16–19].

The financial system is currently undergoing a transition towards green finance, with the goal of achieving the Sustainable Development Goals (SDGs), with some authors directly linking it to the achievement of SDG 8 [20]. In this context, the Network of Central Banks and Supervisors for Greening the Financial System (NGFS) has been created to ensure the financial system transitions towards green finance. Several central banks and international organizations (134 members as of December 27, 2023) are part of it and have pronounced themselves in favor of more sustainable finance and economic growth [21]. Thus, preserving the environment and sustainability ought to be among the core values of CBDCs and can be influenced by the latter's design. According to recent literature, public policies should prioritize the promotion of sustainable finance via CBDCs, as they can reduce emissions by lowering energy consumption [22]. According to some authors, CBDC-related transactions could consume less energy than credit card ones [23,24]. Little literature exists related to CBDC sustainability, according to the authors' best knowledge. Jaimes Becerra et al. (2023) [25] and Náñez Alonso (2023) [26] created a country classification based on the sustainability of their potentially issued CBDCs and categorized countries depending on how "green" their potential CBDCs will be.

A CBDC literature review using the PRISMA method and VOSviewer have not yet been performed, nor a review encompassing such a high number of articles. Ozili [12] performs an academic review by analyzing CBDCs, with a focus on their definitions, CBDC types and designs, the CBDC development stages around the countries, their role within central banks, potential benefits, as well as their potential impact on financial stability and the privacy aspects, before reviewing seven articles related to CBDC research in Asia, Africa and Oceania, thus expanding similar reviews performed in 2020 [27–29]. The most recent systematic literature review (2024) used a text mining approach to analyze 191 CBDC-related abstracts in order to identify the primary research themes [30].

The aim of this review is to contribute to the literature by examining the different researched aspects of CBDCs. Specifically, it focuses on reviewing the available literature on CBDCs by pointing out their positive, neutral, and negative aspects. The goal is to present a thorough analysis of the body of research, including a range of topics such as the consequences for society, the economy, technology, law, and the environment, but also to understand the intersections between blockchain technology, digital currencies, and sustainability, such as energy and environmental effects. To this end, a VOSviewer bibliometric analysis, followed by a comprehensive systematic literature review (SLR) of recently published scientific articles related to CBDCs, was conducted. Five main research clusters, illustrating the main investigated topics as well as the strongest keywords that hint towards the development trends and the research development direction between 2020 and 2022 have been identified with the help of VOSviewer. AMSTAR, DistillerSR, EppiReviewer, ROBIS, and SRDR were the screening and quality evaluation tools employed for study eligibility criteria, design screening and content selection, text analysis data extraction, methodological quality predictors, and reliable and reproducible evidence assessment. The articles were selected from the Web of Science (WoS) and Scopus, covering the period spanning from 2017, when the first article was published on this topic, to July 2023, when the analysis was performed. Following the article extraction, the PRISMA

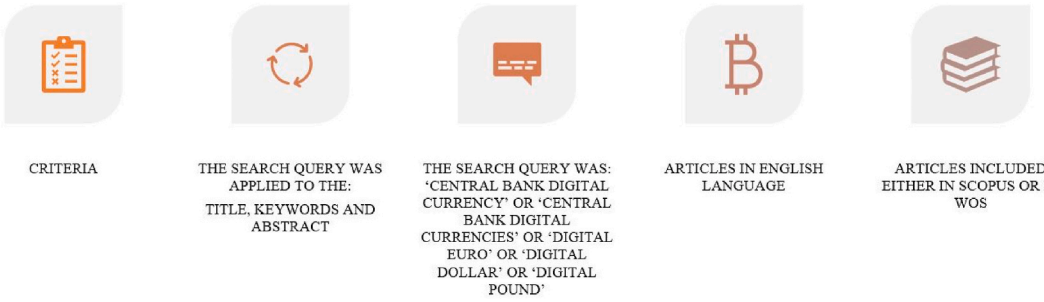

Fig. 1. Applied search criteria. Authors' own illustration.

method was used in order to narrow down the relevant contributions. In the first step, only journal articles were extracted (conference proceedings, books, reviews, and book chapters were excluded) and double entries were removed (some articles appeared both in the WoS and Scopus). In a second step, the articles were manually screened by the authors, who read their titles and abstracts, and the irrelevant ones were removed from the analysis after having been categorized into eight categories. The remaining articles (747) were uploaded into VOSviewer and included in the systematic literature review.

The research question, following the identified research gap, is: What are the patterns and emerging research areas related to CBDCs and how will they evolve in the next few years? This review aims to cover the main research developments surrounding CBDCs that could contribute to future research evolutions. The novelty of the review stems from the analysis of the sustainability aspects surrounding digital currencies, providing valuable insights and tracing the evolution of research in this field. On the one hand, according to research, digital money can be used to increase financial and payment options for initiatives and activities related to sustainable development [20]. On the other hand, both texts of the public consultation on a CBDC created by the Eurosystem (digital euro) and the one created by the FED (digital dollar) do not seem to include any specific questions and statements regarding sustainability, meaning that the general public is not made aware of this aspect [31].

2. Research method

The research question around which this analysis revolves is: What are the trends, patterns, and emerging research areas related to CBDCs, and how will they evolve in the next few years? The purpose is to explore relevant research related to CBDCs and analyze the publication output over time to identify the evolution of CBDC research, with a focus on sustainability aspects. Moreover, with the help of VOSviewer, the authors identified the main research themes and developments during the analyzed period by keyword and keyword co-occurrence analysis.

Glass (1976) [32] defines meta-analysis as secondary research studies carried out with the intention of aggregating the findings of research in particular disciplines. The primary result of meta-analysis is the rigorousness of science, which stems from the systematization of research literature and the afferent process and implicitly allows the accumulation of empirical data in a certain research area [33]. In a variety of research areas, the PRISMA approach is considered the most effective and relevant tool for generating insightful systematic qualitative reviews. It encourages scientists to explain the reasoning behind the review, the steps performed, and the findings in an open, representative, consistent, and honest way [34].

In this regard, the authors relied on the Khan et al. (2002) [35] five-step methodology, combining both the quantitative and qualitative literature review, which included defining the research question, determining the pertinent works for conducting the review, evaluating the relevance of the studies, summarizing the data, and analyzing the results. Exclusion and inclusion criteria were also applied: upon identification of publications about CBDCs in the WoS and Scopus, only those in English were retained. Moreover, publications that did not fall into the category of articles were excluded (such as book chapters, conference proceedings, and reviews). Articles that contained no information regarding CBDCs were also excluded and grouped into eight categories, which were created by the authors using the method of qualitative analysis (Corporate Governance and Risk Management; E-commerce and Digital Business; Financial Markets; FinTech and Digital Finance; Monetary Policy and Economic Stability; Music; Sustainability and Environment; Other) (Fig. 2). Most of the excluded articles had a financial focus but were not at all related to CBDCs or their sustainability aspects. Other articles focused on environmental or music topics. Following the narrowing down of the relevant articles via the PRISMA method, the authors used VOSviewer to create a co-occurrence keyword matrix, a density map, and an author country analysis, thus highlighting the main research interests and directions, before diving into the actual content of the articles and grouping them around articles focused on positive, negative or neutral aspects of CBDC research, with the aim of summarizing the main features and reviewing the recent developments in CBDC-related research. A focus was also placed on CBDC research around sustainability and green finance.

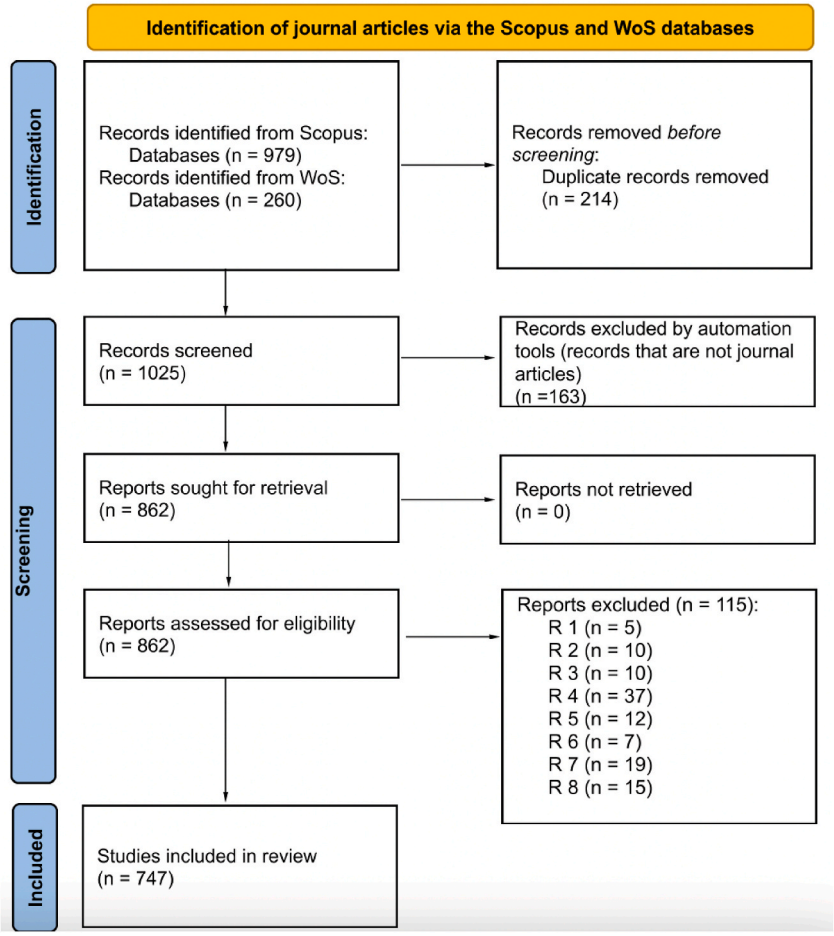

Fig. 2. PRISMA flow chart: Narrowing down of CBDC-related articles in the WoS and Scopus.
*Note: Reasons for exclusion - Reason 1: Corporate Governance and Risk Management; Reason 2: E-commerce and Digital Business; Reason 3: Financial Markets; Reason 4: FinTech and Digital Finance; Reason 5: Monetary Policy and Economic Stability; Reason 6: Music; Reason 7: Others; Reason 8: Sustainability and Environment.
Source: authors' own analysis.

Table 1
Research strategy using SCOPUS and the WoS databases. Authors' own illustration.

Steps	Process	Input	Output
1	Search strategy	**Searched field:** research in English language related to CBDCs **Keywords**: 'central bank digital currency' OR 'central bank digital currencies' OR 'digital euro' OR 'digital dollar' OR 'digital pound' AND (LIMIT-TO (LANGUAGE, "English")	Boolean operators ('OR' and 'AND')
2	Search limitation	The data were selected for the time interval from 2017 to 2023. No specific categories were chosen.	
3	Results	The results were exported in '.csv' and '.xls' format and were imported in Zotero, in order to be prepared for later use in VOS viewer.	1 '.csv' file and 1 '.xls' file were created from SCOPUS and Web of Science, containing important and necessary bibliographic data for analysis.
4	Data cleaning	The files were imported into Zotero software for the purpose of cleaning and removing duplicate studies, as well as for the analysis of the relevant bibliographic data. Once the cleaning action was performed in Zotero, the resulting data was imported into VOSviewer.	The software resulted in 747 publications for the final analysis in VOS Viewer.

Table 2
VOSviewer thesaurus for articles related to central bank digital currencies. Authors' own presentation.

label	replaced by	label	replaced by
block-chain	blockchain	Distributed ledger technology (dlt)	distributed ledger technology
blockchain technology	blockchain	Distributed ledg technology	distributed ledger technology
CBDC	central bank digital currency	dlt	distributed ledger technology
central bank digital currencies	central bank digital currency	e-money	electronic money
cbdc	central bank digital currency	Energy utilization	energy consumption
Cbdcs	central bank digital currency	Financial markets	financial market
central bank digital currency (cbdc)	central bank digital currency	Humans	human
cryptocurrencies	cryptocurrency	Literature reviews	literature review
Central banks	central bank	Monetary policies	monetary policy
central banking	central bank	Payment	payments
Cross-border	cross-border payments	Payment system	payment systems
Crypto-assets	crypto assets	Smart contracts	smart contract
digital currencies	digital currency	pandemic	COVID-19
decentralized	decentralization	defi	decentralized finance
Decentralization	decentralization	investments	investment
digitalization	digitalization	privacy	privacy protection
digital money	digital currency	stablecoin	stablecoins
Digital payments	digital payment	sustainable development	sustainability
distributed ledger	distributed ledger technology	Technology	technology adoption

3. Results

3.1. Determining the pertinent and relevant articles through inclusion and exclusion criteria

The WoS and Scopus databases have been used for extracting relevant articles included in the analysis within this review. When performing the search, the authors wanted to uncover the patterns, trends, and emerging research perspectives that are related to CBDCs. Therefore, a search has been performed by using keywords that have been used by the authors in the title, keyword, or abstract sections of both the WoS and Scopus databases. The applied inclusion and exclusion criteria are detailed in Fig. 1. The following inclusion criteria were considered when selecting the articles: full articles in English language that are indexed in either the WoS or Scopus databases and that included the following terms: *CBDC* or *central bank digital currency* or *central bank digital currencies* or *digital currency*, starting with the first paper identified on the topic (in 2017) until the date when this article was written, i.e., July 2023.

Table 1 below illustrates the methods and applied criteria used to identify the relevant journal articles in the WoS and Scopus databases by using the advanced search option within each database before uploading the results into Zotero. Upon identification of 1239 articles (979 stemming from Scopus, by using the search query "central bank digital currency" OR "central bank digital currencies" OR "digital euro" OR "digital dollar" OR "digital pound" AND (LIMIT-TO (LANGUAGE, "English") and 260 stemming from WoS, by using the search query TS=("central bank digital currency" or "central bank digital currencies" or "digital euro" or "digital dollar" or "digital pound"), 214 duplicate records were removed by using the merge duplicates function of Zotero.

Following this, the exclusion criteria were applied. Using Zotero, all remaining records were screened, and those that did not fall into the category of journal articles (i.e., 163 records) were removed, so that 862 articles remained. The authors assessed their eligibility, and another 114 journal articles were excluded because they did not fully or partially cover the topic of central bank digital currencies. This analysis was performed manually by the authors, who read the title and abstract of each article to make sure it fully or partially covered the topic of CBDCs. The authors also performed an additional step by grouping the excluded articles into eight main categories created by them (Fig. 2). This allowed for a double check regarding the decision to exclude those articles and for more investigations. The category containing the most excluded articles was the one related to FinTech and Digital Finance, which includes articles that were finance-related but without a CBDC focus or including CBDC-related information at all. After narrowing down the initially exported articles, 747 articles remained and were included in VOSviewer for further analysis. The research strategy can be found in Table 1.

Fig. 2 presents an overview of the process of narrowing down the WoS and Scopus articles by the authors through the use of the PRISMA flow chart. The first section presents the number of initially exported articles, out of which 214 were removed before screening, given that they were duplicates. The screening section contains the exclusion criteria (publications that did not fall into the category of journal articles and publications that were excluded following a manual verification by the authors, grouped around eight exclusion criteria), and the last section contains the number of articles included in the review (747 records).

3.2. Interpretation of findings

Following identification of the relevant articles to which the above-mentioned inclusion and exclusion criteria have been applied (Fig. 2), the bibliometric analysis was performed using VOSviewer, a software that creates bibliometric networks and co-occurrence maps [36]. 747 articles were inserted into VOSviewer and the attraction parameter was set to 2, while the repulsion parameter was set to 1, in order to obtain a qualitative visualization, as recommended in the VOSviewer manual. These parameters influence the layout of items on the map, and the above-mentioned values are the default ones [37]. Table 2 illustrates the thesaurus compiled and inserted

Table 3
Interpretation of VOSviewer co-occurrence clusters. Authors' own presentation.

Cluster	Color	Cluster Main Theme
1	Green	Digital Finance, Sustainability and Fintech
2	Violet	Blockchain and Decentralized Technologies
3	Red	Digital Currency and Financial Innovation
4	Yellow	Privacy and Data Regulation in the Digital Age
5	Blue	Digital Economy and the Impact of Digital Assets

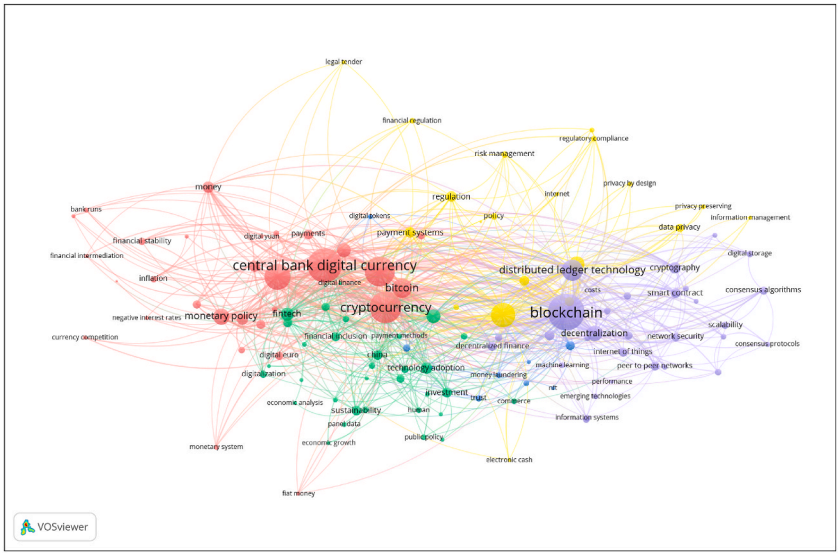

Fig. 3. VOSviewer co-occurrence mapping regarding CBDC-related articles from Scopus and WoS. (own illustration).

into VOSviewer. The thesaurus contains labels that VOSviewer replaces with another because they define the same term or concept. This ensures the generation of a more accurate co-occurrence map. For example, the terms 'CBDC', 'central bank digital currencies' and 'cbdcs' were all replaced by the term 'central bank digital currency', as they all incorporate the same term and are synonyms. Terms written in British and American English were merged (i.e., the term 'decentralization' has been replaced by 'decentralization'). Plural forms were assimilated to their singular form, and abbreviations were replaced by the full term.

The minimum number of co-occurring keywords was set to 5, meaning that a keyword was visible on the co-occurrence map only if it appeared at least five times. This resulted in 131 keywords. Out of these, the following keywords were manually excluded because they were not deemed to be relevant to the field of CBDCs: "current", "article", "bibliometric analysis", "e42", "law", "literature review", "sales'' and "surveys". As a result, 123 keywords remained and were used to create the co-occurrence map in VOSviewer. Table 3 illustrates the main themes around which the 5 clusters (having a minimum size requirement of 5 keywords) revolve. The clusters in the below table have been deduced through the analysis of the authors.

All the five clusters revolve around finance, technological developments, and digitalization. The terms "digital finance", "sustainability", and "fintech", as well as more general financial terms like "commerce" and "government", are all included in the ecosystem of digital finance, sustainability, and fintech, which revolves around the intersection of finance and technology in a digital, partially green, sustainable context. The above-mentioned clusters identify the main research interests around CBDCs.

The first cluster focuses on aspects related to digital finance in general, fintech, and their sustainability. China and China-based research are strongly correlated to this cluster, together with terms such as fintech, technology adoption, investment, and digitalization. This suggests an interest in developing an alternative to the traditional financial system. Given fintech's fast development, the traditional financial system is now faced with the opportunity of using alternative means, such as CBDCs, for the achievement of monetary policy objectives. Central banks have used a variety of nonconventional measures that seem to have reached their efficiency limits, especially when it comes to their interest rate mandate. CBDCs could also help in eliminating the zero lower bound constraint and optimizing the interest rate policies of central banks [38].

The second cluster revolves around blockchain, DLT (distributed ledger technology), decentralized finance, and emerging technologies (such as the Internet of Things (IoT), machine learning, and smart contracts). This cluster hints at the debates taking place at the moment regarding the CBDC infrastructure and design to be used. No consensus has yet been found regarding CBDC design, as central banks need to be sure that, once they choose a technology for CBDCs, they will also be able to adapt it so as to stay in line with the latest regulations and technological developments [12].

The third cluster is centered on CBDCs in relation to fiat money, bitcoin, the digital yuan, cryptocurrencies as a whole, currency

Table 4
Number of occurrences and total link strength of each keyword. Authors' own analysis.

No.	Keyword	Occurrences	Total link strength	No.	Keyword	Occurrences	Total link strength
1	central bank digital currency	210	181	16	sustainability	26	25
2	blockchain	200	191	17	China	25	23
3	cryptocurrency	166	155	18	money	25	25
4	digital currency	119	112	19	payment systems	23	22
5	central bank	115	113	20	technology adoption	23	21
6	electronic money	82	81	21	banking	22	22
7	bitcoin	68	64	22	currency	22	22
8	distributed ledger technology	60	60	23	security	20	19
9	monetary policy	60	52	24	cryptography	19	19
10	fintech	46	41	25	financial inclusion	19	19
11	privacy protection	37	35	26	financial stability	19	17
12	stablecoins	37	36	27	cash	18	17
13	decentralization	32	30	28	regulation	18	17
14	covid-19	29	26	29	surveys	18	18
15	finance	28	28	30	digital euro	17	16

competition, and the connection between CBDCs and inflation, interest rates, financial stability through monetary policy, bank runs, and digital finance in general. It becomes clear that CBDCs, depending on their design and on the specifics of the issuing country or institution, will have an impact on both a micro- and macroeconomic level, and that the institutions issuing such currencies should not implement them until enough research is done on what design is best in relation to the goals to be achieved.

The fourth cluster addresses data privacy and financial and data regulations related to privacy in the digital age. It means that ensuring privacy should be a top priority when choosing the CBDC design. This is already the case for cryptocurrencies, meaning that central banks could use their design if it aligns with their needs. One must note the irony of central banks wishing to use the cryptocurrency design to issue CBDCs, given that cryptocurrencies first appeared as an alternative to the traditional banking system.

The fifth and last cluster focuses on the digital economy and the impact of digital assets in general. It also takes into account money laundering and trust in the context of the digital economy. On the one hand, CBDCs could constitute a powerful tool in fighting money laundering within the digital economy, while on the other hand, central banks need to make sure citizens trust their actions if they want their mandate to be efficient. CBDCs could help enhance or lose citizens` trust in central banks, depending on how successful their implementation is, how secure they are, and their adoption level.

Fig. 3 represents the co-occurrence matrix built upon the most frequent keywords (with a minimum of 5 keywords) used by the authors in the field of CBDC, thus illustrating the main research interests as well as the density of the keywords. It is visible that the three hottest points are the ones around the term "central bank digital currency", which acts as the main topic of this research review, closely followed by the words "cryptocurrency" and "blockchain". The density hot spots (in yellow) indicate keywords that are strongly connected with each other and are crucial in the actual research landscape. Interesting to note is also the fact that opposing terms, showing CBDC advantages and disadvantages or two sides of the same coin, such as trust and DeFi and money laundering or inflation and negative interest rates, privacy, and cryptography, are part of the same clusters, meaning that research is comprehensive, considering both negative and positive aspects.

Aspects of blockchain technology, such as consensus algorithms, protocols, and cryptography, are included in the cluster for blockchain and decentralized technologies, along with ideas like decentralization, decentralized financing (DeFi), information utilization, and IoT, which tie into these topics. It includes the fundamental ideas and innovations that underpin the decentralized character of blockchain systems, as well as some of their possible use cases.

The topics surrounding digital currencies and financial innovation, and its effects on the banking industry, are the focus of the cluster "Digital Currency and Financial Innovation in Banking". Different types of digital currencies and their possible roles in the financial system are discussed by the terms "bitcoin", "cash", "CBDC", "digital euro", "fiat money", and "currency competition". The terms "central bank" and "bank runs" are included, indicating the importance of these occurrences in relation to central banking and financial stability. Furthermore, the reference to "COVID-19″ raises questions about the possible effects of digital currencies and financial innovation in crisis situations and the other way around.

The themes relating to privacy, data protection, financial regulation, and risk management in the context of the digital era are covered by the cluster Privacy, Data Regulation, and Risk Management in the Digital Era. The concepts of "anonymity", "data privacy", "privacy by design", and "privacy protection" all concern the protection of sensitive and private data. In the age of sophisticated data technologies and digital connections, the terms "big data," "artificial intelligence", "internet", and "information management" emphasize the importance of these privacy- and data-related concerns. The terms "electronic cash", "electronic money", and "legal tender" are also included, which suggests that the discussion is concentrated on digital payment systems and their consequences for privacy and regulation. The terms "financial regulation", "regulatory compliance", "policy", "regulation", "risk assessment", and "risk management" emphasize the importance of regulatory frameworks and risk management techniques in the world of digital finance.

The major themes of the cluster centered on issues relating to the digital economy, digital assets, and their larger economic and social impacts, include the digital economy and the impact of digital assets. The terms "digital transformation" and "economic and social effects" imply a focus on how various facets of the economy and society are changing as a result of digitalization. The terms "digital tokens", "NFT" (Non-Fungible Tokens), and "trust" are all present as well, demonstrating a particular interest in blockchain-

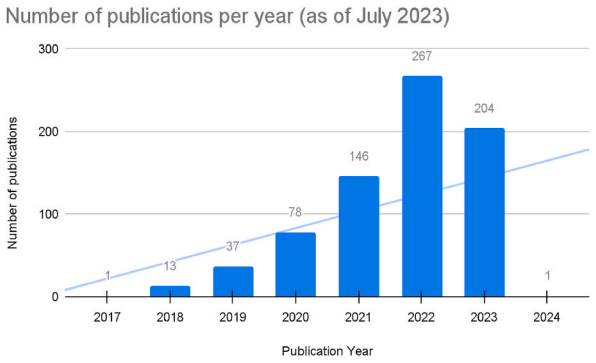

Fig. 4. Number of publications per year (as of July 2023. Only the period January–July was taken into account in 2023) (own illustration).

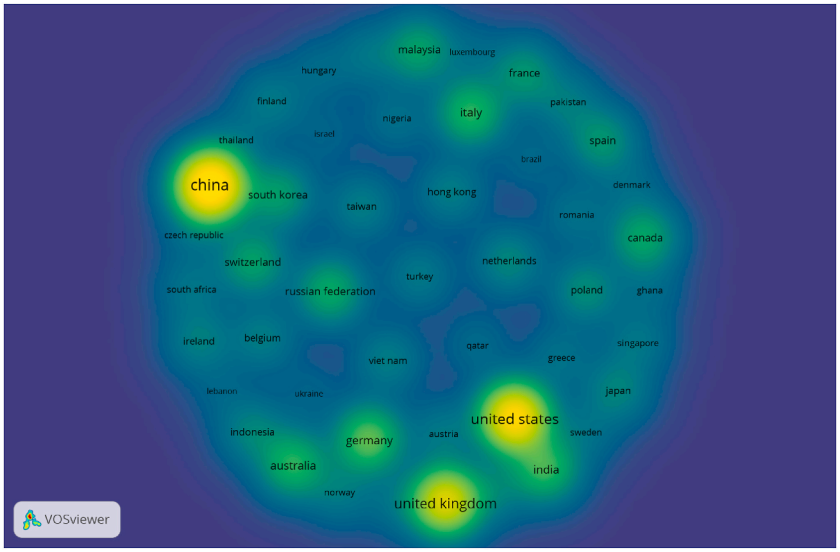

Fig. 5. Authorship country analysis related to CBDC research (own illustration).

Table 5
Co-citation analysis by author. Authors' own analysis using VOSviewer (own presentation).

Reference	Number of citations	Link strength
European Central Bank	39	302
BIS	39	244
Auer, R.	33	186
Sveriges Riksbank	18	154
Bank of England	17	149
Boar, C.	23	124
Panetta, F.	11	89
Brunnermeier, MK.	12	81
Barrdear, J.	11	79
Mersch, Y.	12	61
Nakamoto, S.	13	56

based digital assets and the significance of trust in the digital economy. Additionally, the term "economics" implies a deeper investigation of economic theories and tenets in the context of the digital world. The inclusion of "money laundering" may also suggest that difficulties and concerns related to digital assets and their possible use in illegal operations have been considered.

The highest frequency keywords within the above-pictured clusters (Fig. 3) are illustrated in Table 4 below, which illustrates both the total count of occurrences and the total link or connection strength of each keyword, with a higher value meaning a stronger link.

Fig. 4 depicts the evolution of the number of publications surrounding CBDC-related articles. The trend is upward, with such research almost doubling year over year. It must also be noted that the export was performed in July 2023, at the time of writing this

Table 6
VOSviewer bibliographic coupling analysis by source (own presentation).

Source	Number of documents	Number of citations	Total link strength
IEEE Access	17	504	152
Sustainability	21	265	119
Journal of Monetary Economics	7	124	97
China Economic Journal	9	123	88
Research in International Business and Finance	27	118	314

Table 7
2020–2022 evolution of CBDC research. Authors' own presentation.

Main research developments	Year	Colour
Monetary systems, scalability, legal aspects	2020	Blue
Digital tokens, cryptocurrencies, payment scalability, legal aspects, privacy	2021	Green
Currency regulation, currency competition, trust, innovation, DeFi, decentralization, digital currencies (digital euro, digital yuan)	2022	Yellow

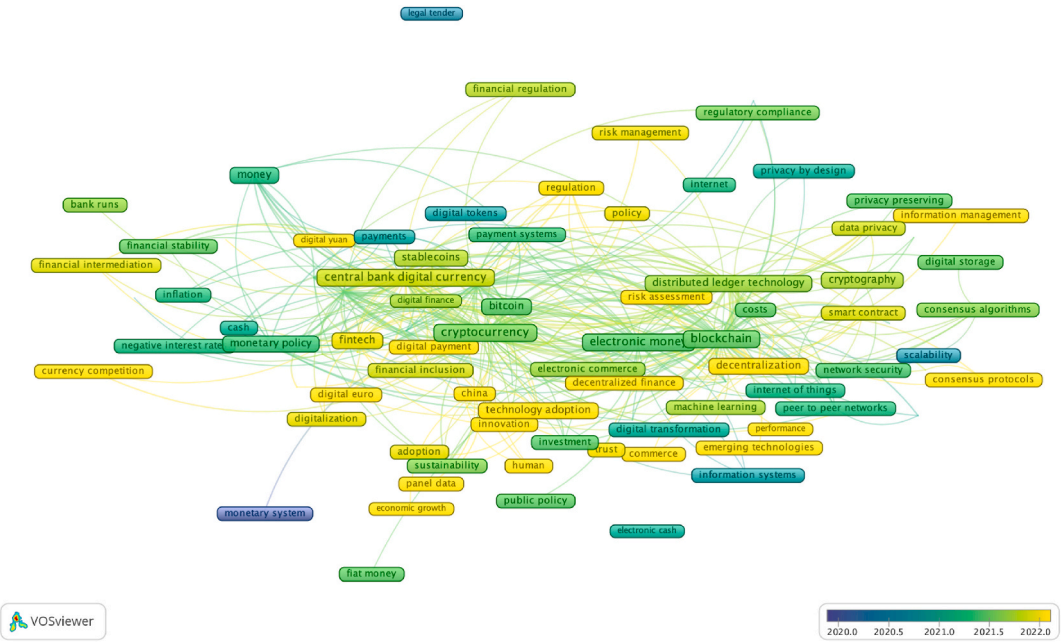

Fig. 6. VOSviewer overlay keyword visualization for the period 2020–2022 (own illustration).

article, so the column related to 2023 publications is likely to show a higher number by the end of the year, in case the upward trend continues. The first recorded CBDC-related article was published in 2017. 2018 featured 13 CBDC-related publications, while in 2019 the number of publications reached 37, before growing to 78 in 2020. The number surpassed 100 in 2021, with 146 articles. 2022 was a fruitful research year, with 267 published articles. At the time of writing (July 2023), 204 articles have already been released.

Given the sharp increase in the number of CBDC publications, a further step was taken to identify the countries publishing on the topic via a co-authorship country analysis. The results are visible in Fig. 5, which shows the countries having published a minimum of 5 CBDC-related documents, with a minimum number of citations for each country being 5. Of the 107 countries analyzed for the purpose of this article, 48 met the above-mentioned thresholds. The USA, followed by China and the UK, are leaders when it comes to total link strength, number of citations, and number of published documents. They are followed by Australia, India, Canada, Germany, and Switzerland.

The most cited authors and institutions are detailed in Table 5, which was compiled using the co-citation analysis type by author (the relatedness of authors is compiled by VOSviewer based on the number of times they are cited together). It becomes obvious that banking institutions, such as the ECB, BIS, Sveriges Riksbank and Bank of England, appear at the top of the list, followed by individual authors that lead research in this field.

The bibliographic coupling analysis by sources revealed that the most cited sources by number of citations were *IEEE Access*, *Sustainability*, *Journal of Monetary Economics*, *China Economic Journal*, and *Research in International Business and Finance* (Table 6).

Upon analysis of the overlay visualization generated via VOSviewer (Fig. 6), the research developments between 2020 and 2022 are visible as a whole. Keywords from 2020 are marked in blue, those from 2021 in green, and those from 2022 in yellow.

The evolution of the main research developments has been summarized in Table 7, based on the information compiled via VOSviewer in Fig. 6.

It is noteworthy that 2022 publications focus on keywords such as currency competition, regulation, digital yuan, digital euro, trust, innovation, digital payment, emerging technologies, and decentralized finance. Important themes emerge, which can indicate potential future research directions related to CBDCs. One of them relates to currency competition. The focus on currency competition suggests that researchers are interested in understanding how CBDCs might impact existing fiat currencies and other digital currencies, including stablecoins and cryptocurrencies. Another theme is related to regulation. The emphasis on regulation highlights the importance of understanding the legal and regulatory frameworks surrounding CBDCs. This may include considerations related to monetary policies, financial stability, and consumer protection. Also noteworthy are research interests around specific digital currencies, such as the digital yuan and the digital euro. The specific mention of the digital yuan and digital euro indicates that researchers are paying attention to CBDC initiatives in major economies. Understanding the experiences and developments of these digital currencies could have implications for other countries considering their own CBDC implementation. Trust and innovation also emerge as themes. Trust is a critical factor in the success of any currency, including CBDCs. Research into trust likely explores how CBDCs can gain public support and how their design can enhance security and privacy. The focus on innovation suggests an interest in exploring novel approaches and technologies to improve CBDC offerings, exposures, and distributions. The prominence of digital payments and emerging technologies indicates a growing interest in understanding the technical aspects of CBDCs. This could include exploring the potential of blockchain technology, smart contracts, and other innovations to enhance CBDC infrastructure and functionalities. The mention of decentralized finance suggests that researchers are looking into how CBDCs could interact with the growing DeFi ecosystem. This might involve studying potential integrations, opportunities, and challenges arising from combining CBDCs with DeFi platforms.

Overall, these highlighted keywords from 2022 suggest that future research related to CBDCs may focus on the practical implementation, policy implications, and technical aspects of CBDCs. It indicates a shift from foundational research towards more specific, applied, and practical considerations. Researchers may explore how CBDCs can coexist with other currencies, how to effectively regulate them, and how to leverage emerging technologies to make CBDCs more efficient and secure. Moreover, the emphasis on innovation indicates an ongoing drive to push the boundaries of CBDC applications and explore new possibilities for the digital economy.

4. Discussions

SLRs are useful in assisting researchers to obtain a recent overview of scientific literature, in discovering new possible study subjects, in assessing pre-existing theories, and in generating development and knowledge advancement strategies. SLR are seen to be pertinent in social science research as crucial instruments for enhancing study and assisting with decision-making [39–41]. It was deemed relevant to take a further step and perform a SLR on the 747 articles extracted from Scopus and the WoS. Following the VOSviewer analysis of overlay keywords and term co-occurrence, the 747 articles were split into articles with a positive, neutral and negative focus and analyzed further in subsections 4.1, 4.2 and 4.3.

4.1. Positive CBDC research

Multiple publications with favorable statements about CBDC attached to them were found following revision of the article titles and abstracts, as well as other positive themes that kept coming up in relation to Central Bank Digital Currencies (CBDCs). Positively oriented articles investigate the potential advantages of CBDC development for financial institutions and citizens alike, sometimes with an emphasis on sustainability. It is also noticeable that there is a growing interest in CBDC development.

The first positive theme concerns financial inclusion. Several articles focus on the potential of CBDCs to promote financial implementation and ease of payment. By offering simple and convenient digital payment options, CBDCs can enable citizens, especially those with poor access to traditional banking services to be part of the financial system, indicating that CBDCs can help make them more accessible to underserved populations. The only pre-requisite is for citizens to have access to the technology needed to make payments, usually in the form of smartphones. Following COVID-19, the payment landscape changed and a shift towards cashless transactions happened, with citizens increasingly using means of electronic payment [42]. CBDCs would take the trend one step further [41,43–45].

Efficiency and innovation are two other repeating themes. CBDCs are viewed as a boost for financial innovation and improved payment system efficiency. Digital currencies can shorten transactions and settlement times and lower their costs, leading to a more efficient financial environment. The financial landscape could be drastically altered by CBDCs, and this could have an impact on how businesses are conducted. CBDCs are seen as a transformational technology that has the potential to completely alter the financial industry, being a driving force behind the financial sector's digital revolution. Their implementation may encourage the use of fintech products, fostering the development of a more modern, digital economy [46–51].

The potential implications of CBDCs on monetary policy and financial market stability are covered in a number of studies. CBDCs can provide new tools for central banks to efficiently carry out monetary policy and strengthen the mid-to long-term stability of the financial system. The main features of central bank digital currencies, their possible effects on the monetary and credit systems, and the significance of monetary innovations in the context of the digital economy are covered in certain articles. Digital currencies are

examined from the point of view of building a policy framework for digital money. CBDCs may have advantageous effects on the macroeconomic and financial systems, and analysis is performed regarding such possible favorable macro-financial effects [52–55].

Also widely discussed is CBDC adoption on a regional and international level [56]. The Eurozone [57] is generally interested in CBDCs, with some studies focusing on particular nations, such as Germany [58] or Hungary [59]. Numerous papers address the improvement of the US monetary system that will result from the adoption of digital cash [60,61], or they analyze the exchange rate between the US dollar and the Chinese yuan, whether it is in physical or in digital form [62]. Positive developments are highlighted with respect to the Chinese central bank's (CB's) digital currency (e-CNY) project, suggesting progress and possible outcomes of its implementation [63], thus making China a leader in terms of development and collaboration in the adoption of digital currencies. According to previous studies, India is progressing with its e-rupee digital currency [64] and behavioral intention indicators are used to address the perceived dangers and benefits of its implementation [65]. According to research [66] on the potential adoption of a CBDC by Japan, this currency would be utilized virtually daily. The existence of a project focused on the digital euro indicates progress in the research and evaluation stage of CBDC development in the Eurozone [67], within a project that is moving forward and demonstrates a positive attitude towards researching the viability of a digital euro [57].

4.2. Challenges regarding CBDCs

Following an examination of the article titles and abstracts, several papers have been found that point to various issues and difficulties related to the introduction and use of CBDCs. The first subject has to do with legal restrictions and constitutional issues in the EU [68–70]. According to several authors, the legal restrictions and difficulties [71] are due to a lack of transparency, a significant danger of bank runs, and a lack of trust on the part of the issuer and receiver. If CBDCs will be treated legally as traditional money, the main CBDC types that central banks throughout the world are currently considering are not feasible in the long term [72]. There may be constitutional restrictions that make the establishment of central bank digital currencies difficult outside of the European Union as well. For example, from a Jordanian and Islamic point of view, digital currencies are incompatible with Islamic law in their current form and should abide by the rules of Islamic banking [73]. China's lawmakers could encounter legal problems as well, as a result of the adoption of a legal digital currency. These challenges, such as the preservation of individual privacy, disputes over currency sovereignty, and potential cross-border crime hazards, may occur on both a national and international scale [74]. The evolution of the US dollar payment system could also face legal challenges [75]. Even if digital assets have been regulated in the United Kingdom since 2019, several unclear issues and weaknesses exist within the regulatory framework [76].

The possible concentration of power and control by central banks over the digital currency system, which could generate difficulties with financial stability, personal privacy, and individual autonomy, resulting in a lack of trust by citizens, is another reoccurring negative theme [77–79]. According to some authors, the use of CBDCs should not result in a situation where central banks, having significant control over the digital currency system, could hurt the privacy and civil liberties of citizens [80]. In addition to the privacy concerns, worries also arise regarding the integrity of the afferent payment systems and with regard to the cross-border features of CBDCs and audit risks [81,82]. The protection of personal information and the right to privacy must coexist with the suppression of financial crime when central banks adjust the design criteria for CBDC. Guidelines are needed, to ensure that data is handled responsibly and that access is limited to public bodies carrying out their duties [83].

Technological challenges are also mentioned in the literature. The unequal technology between financial markets and the appropriate supervisors makes them harder to implement [84], as does the fact that the DeFi technologies supporting them present inherent risks that may obstruct supervisors' oversight or promote illegal activity [85–87]. To ensure that blockchain may be used within the IoT framework and to increase the potential application possibilities of each existing infrastructure, the current IoT infrastructure needs to be modified [88]. Additionally, the infrastructure must be safe and easy to use, and it will need high-speed internet, which could be difficult in some areas [89].

4.3. Neutral CBDC research

Numerous articles discuss CBDCs in an impartial manner and list their advantages and disadvantages. To gain some understanding of central bank research on digital currencies, literature provides an outline of recent advancements on the topic. CBDCs are seen as a liability for the central bank because they have properties akin to currency. There are justifications for issuing a CBDC and benefits of doing so, such as the need to increase financial inclusion of options, improve the efficiency of digital payments, and rework monetary policy. These reasons also lead many central banks to consider issuing CBDCs. The studies also advise against exaggerating the potential advantages of CBDC due to its conflicting goals and limited design. Future research should focus on identifying the optimal CBDC design to satisfy as many goals as possible, on dedicating empirical research on the connection between CBDCs, credit costs, and financial stability, the limitations on how much of a CBDC a consumer can possibly hold from a regulatory perspective, as well as regional and national case studies on the best cases of CBDC design [12,20,54].

The universe of cryptocurrencies and CBDCs is described as it develops, and an evaluation of their potential future uses is provided. The main historical and social factors that have influenced the current boom in digital currencies are highlighted. The advantages of using a cryptocurrency in a diversified portfolio from the standpoint of investments are presented, along with an analysis of other factors that should be considered when it comes to asset allocation considerations. Additionally, the effects of using such digital currencies on society, the environment, and governance are examined. These essential components are offered in order to provide a thorough understanding of the changing environment of digital currencies, including both advantages and disadvantages [90]. Research demonstrates the diversity of CBDC aspects to be considered, including its intricate restrictions, technical requirements for

adoption, attributes, and prospective effects, but also Fintech advancements, monetary policy ramifications, feasible implementation options, and elements like their effect on money laundering and payment digitalization [91].

Research also focuses on blockchain technology [92,93] and blockchain interoperability, covering digital money, cross-chain asset transactions, supporting technologies, as well as open challenges and future research objectives. Because CBDC development is accelerated due to ongoing development in the area of blockchain technologies and cryptographic currencies, functional and non-functional CBDC design requirements are analyzed in the literature and a review of CBDC schemes based on blockchain methods is actioned (permissioned and permissionless blockchains). The difficulties with these CBDCs, including scalability, performance, and cross-chain compatibility are also outlined, along with recommendations for CBDC designs based on blockchain [94]. Other studies focus on the technological divide between blockchain and fintech applications, presenting a taxonomy of use cases spanning both public and private blockchains for each of the areas in which blockchain is already in use as an additional technology to conventional systems. Blockchain has both positive and negative features because it is still thought to be in its infancy, particularly when it comes to financial use cases. It is crucial to be aware of all open research questions in this area, of the benefits, as well as of open research obstacles pertaining to different facets of the protocol and application layers of the blockchain [95].

4.4. Sustainability and CBDCs

Out of the 748 articles, only 31 focus on sustainability or green finance aspects, accounting for 4.14 % of the articles included in the literature review. They range from presenting literature reviews to models applied to blockchain and the need for support for green initiatives, to their influence on monetary policy and community development activities, and to strategies and laws that link digital currency to green finance.

Several articles focus on green finance, carbon neutrality, and the digital economy in general, addressing sustainability aspects in the Chinese market. Research examines how digital technology affects carbon emissions in China and the relationship between blockchain technologies and possible carbon neutrality. The results show that the carbon neutral index (CNI) is influenced both favorably and unfavorably by the blockchain index (BCI) [96]. The benefits imply that the quick development of blockchain technology speeds up the transition to a carbon-neutral state and vice versa, which highlights the role of the technology as a facilitator in China while also mentioning negative effects [96]. The dependence between the construction of digital infrastructure and low-carbon development, using China as an example, is also explored and shows that building digital infrastructure promotes low-carbon development, while at the same time presenting novel approaches for the development of digital infrastructure and low-carbon economies in developing nations [97]. Researchers have gained insights into the carbon emission trading (CET) market, highlighting that market mechanisms could help reduce greenhouse gas emissions. Although CET encourages tactical green innovation, it has little impact on fundamental green innovation. Furthermore, a positive spillover effect of CET on green innovation can be monitored, varying with the level of green innovation, influencing marketization, fiscal decentralization, and governmental environmental concern. The aforementioned research findings are used to develop policies [98].

Research is also interested in whether the digital economy can successfully support green innovation in industrial firms in China, via an analysis of A-share industrial listed businesses (2011–2020) [98]. Results show that green innovation is encouraged by the digital ecosystem. Different types of businesses are significantly differently affected by the influence of digital economic structures and processes on green innovation, with state-owned businesses being more strongly impacted. By increasing public awareness and improving the energy grid, the digital economy fosters green innovation. As a result, optimizing energy use and performing the role of public attention monitor are crucial tactics to support corporate green innovation [99]. Studies also investigate the connection between Chinese SMEs' market success and their culture of green innovation [100] and demonstrate a favorable impact of green innovation culture on product, marketing innovation and market performance, suggesting that SMEs in emerging economies should focus on fostering a culture of green innovation in order to enhance their success on the market.

Research also focuses on the impact of investments on green companies by examining the financing constraints index (FCI) of green sectors' driving variables from 2010 to 2019. The findings demonstrate that Chinese listed businesses are increasingly facing financing limitations on an annual basis and offer legislative recommendations for easing the financial challenges facing green sectors [101]. In order to achieve high-quality economic development, the government should foster an environment that is conducive to investment, financial institutions should change how they allocate capital, and high-tech businesses should expand their access to financing in order to increase their capacity for risk-taking [102]. Foreign direct investment (FDI), a crucial component of China's integration into the global economy, can boost the country's capital accumulation. Furthermore, this can empower the transfer, exposure, distribution and implementation of green technologies. The interdependence between foreign direct investment and the adoption of sustainable, green technologies in China is evaluated, taking into consideration China's provincial panel data from 2007 to 2019 as well as situational data from 30 provinces of China [103].

Research also uses the SEEA (System of Environmental and Economic Accounting) method to calculate the green economy growth as well as the level of digitalization in China, besides developing an evaluation index system. Based on panel data from 2013 to 2019, the internal mechanism and linear link between digitization and the growth of the green sector were explored. It was found that the green economy and digitalization both exhibit a consistent upward tendency, with the former strongly promoting the latter. The mechanism analysis revealed that innovation in green technologies is prioritized and proposed relevant policy consequences, including the development of new digital infrastructures and regulating the use of green energy [104]. The primary goal of businesses is to achieve sustainable corporate growth and ensure shareholder wealth. A panel data test (399 companies) observed that disclosure of ESG policies can promote sustainable growth in contrast to companies that are not disclosing ESG approaches [105]. Moreover, the bottleneck created by decreased total-factor energy efficiency (TFEE) needs to also be overcome in China so that sustainable

development can be achieved. The TFEE values of 30 provincial units have been assessed in mainland China over a 13-year period, from 2008 to 2020 and the effects of human capital development and green finance on regional TFEE in China have been investigated. It has been demonstrated that investments in science and technology, as well as economic development, can raise TFEE across all regions [106].

An analysis of the influence of the digital economy on energy efficiency has been conducted using a fixed-effect model and taking 284 prefecture-level Chinese cities from 2008 to 2018 into account. The study's findings demonstrate that energy efficiency is effectively promoted by the digital economy's growth in China. Furthermore, the R&D innovation effect enhances energy efficiency by reducing wasteful energy usage in the digital economy. The growth of the digital economy has profound implications for modernizing and improving the economic system, enhancing energy efficiency, and accomplishing a green revolution [107]. In this context, sustainable development requires consideration of CBDC's environmental impact. Research seeks to find a correlation between the CBDC pilot program on green investments and sustainable growth in China [108]. One of the results states that the use of CBDCs encourages the issuance of green bonds, focusing on manufacturing businesses and state-owned enterprises. CBDCs furthermore promote green land development and reduce emissions (especially SO2 as well as smoke), thus accelerating green finance, which promotes sustainable development.

The digital yuan is still in its development phase, but China is motivated to issue it as a result of the rise of cryptocurrencies, including Bitcoin, which is banned there, the evolution of big technology firms, and the need for a more stable currency, together with additional macroeconomic tools [12]. It becomes obvious that China is a frontrunner in conducting research around the link between the digital economy and green energy, and that sustainability constitutes one of their major research themes, given their focus on greener cities, less pollution and green innovation, especially in industrial companies, whether private or state-owned [99,101,102].

When it comes to sustainability, other articles focus on blockchain technology and the Energy Internet, in which there are many participants using sustainable energy sources, and some problems, such as the management and control of dispersed sustainable energy sources, are challenging to solve. The banking industry is changing thanks to blockchain, which also presents prospects for significant cost savings and effective banking services. However, due to a lack of sufficient information and expertise on how to deploy the technology, implementing blockchain is difficult. Due to the lack of market-ready blockchain banking products, organizations are unable to realize the value that was promised. Research provides an overview of blockchain use cases, design and implementation factors, and technical approaches in the banking industry. The objective is to provide a primer based on evidence to help practitioners and researchers. The study uses the systematic literature review methodology and examines a total of 45 documents, including 26 scholarly pieces that have undergone peer review and 19 technical reports from the banking sector [109]. According to the findings, experimentation efforts oriented toward the creation of payment systems have increased in the banking sector. The findings also highlight important organizational, technological, and environmental factors. The paper emphasizes that among the crucial technical factors for adopting blockchain banking systems are platform selection, scalability, and durability. Collaboration and governance-related issues are two organizational considerations. The research highlights a number of legal and regulatory problems from an environmental standpoint. The literature on blockchain adoption in banking is still in its infancy, and this study adds to it. A research agenda for further investigation of blockchain applications in the financial industry is also provided by the study. We identify areas of interoperability, governance, security, and privacy where more research is needed [109].

Many of the issues preventing the growth of the Energy Internet can be resolved by applying the technical advantages of blockchain to it. Studies examine the evolution of blockchain and the Energy Internet and offer some references for potential blockchain applications to the Energy Internet. There are various blockchain application scenarios proposed for the Energy Internet, as well as challenges to be addressed [110]. There are many obstacles preventing the adoption of blockchain in the energy industry. Understanding these problems implies the analysis of technological [111], economics, society, environmental, and institutional aspects. Based on a blockchain-based energy system scenario in Japan, each dimension is examined. Scaling's specific difficulties are explored, along with opportunities for overcoming them. A summary of strategic cues is recommended. A holistic and practical approach is generally advocated as being advantageous for the implementation and scalability of blockchain in the energy transition [112].

A reduction in global carbon emissions is urgently required for the energy transition. A key component looking at developing the deep-rooted decarbonization gearing towards a net zero emission economy combined in a market-based strategy seems to be the tracing of emissions in the energy system. When tracing emissions, operators need to have an end-to-end data flow in place connecting carbon sources and sinks, while ensuring the data protection of end users and companies at the same time. This can result in developing a tracing system for carbon emissions that complies with data quality and protection standards, such as verifiability, distinguishability, fractional ownership, and privacy [113].

When choosing the technical characteristics of CBDC, energy consumption and environmental aspects need to be taken into account, along with financial safety, resilience, and design adapted to consumer needs. The CBDC infrastructure can use blockchain technology or traditional database systems, depending on the features and efficiency (in terms of energy, characteristics, and speed) desired for CBDCs. Several studies are in progress, given how intricate the topic is and the number of variables to be taken into account. Institutions such as the European Central Bank are transitioning towards green finance in the context of the low-carbon economy [114] and the authors expect a stronger green focus in future CBDC studies.

Moreover, using social identity theory, research [115] investigates how human economic behavior and views on environmental perceptions can affect the consequences of potential future courses in relation to the environmental problem. There are high levels of uncertainty and the impact of megatrends will affect the future. The variables that affect environmental preferences and, consequently, the many future scenarios are identified through the main components analysis of data derived from a field study carried out in Greece between 2019 and 2020. Moreover, in governance systems, media attention can positively influence the promotion of green innovation during economic fluctuations. Increased corporate social responsibility and fewer financial limitations are two ways that media

attention can support green innovation. Therefore, it is crucial to support businesses' green innovation by paying close attention to the media as an institutional subject [116]. Human economic behavior, the media, and social factors must be taken into account when making investment decisions, given that green finance is the foundation for the development of sustainable financing of environmental projects, enabling a green transition towards economic growth that will be long-lasting and establishing a foundation for maintaining macroeconomic stability based on the creation of fresh alternative finance sources [117]. Before green finance can impact the environment and society, the knowledge about green finance has to be promoted, the definitions have to be refined, government policies and legal frameworks have to be aligned and the available incentives have to be reworked in order to push investors and financial institutions [7]. CBDC research around user adoption states that it will likely be welcomed and used in both rural and urban areas, complementing cash [118] and a focus on green finance could only enhance the adoption level.

Other articles strictly focus on new money [119,120], CBDCs as new financial instruments [121], the digital Euro [122] or various cryptocurrencies and the sustainability-related ecosystem around them [123–127]. By constructing an overview of how modern money is created and combining contemporary heterodox theories and the most recent empirical data, it is suggested that a greater institutional understanding of modern money processes might be useful for enhancing our ability to consider how money generation might more effectively address the needs of the current social and environmental system. Commercial banks have the ability to "create" new bank deposits in customers' accounts, either via customers who "borrow new money into existence" when loans are made by commercial banks, or via central banks that "create new money into existence" or when they buy assets like government bonds from investors, or the government "spends new money into existence." [119,120]. This means that the traditional instruments of central banks to control the state of the economy are no longer sufficient in the face of the ecological transformation the world is now facing. In contrast to climate change, which is a long-term process that will affect supply circumstances, conventional techniques are designed to manage short-term variations in demand. CBDCs are a potential new instrument. A network of community development banks could be partially financed by loans from CBDCs or other means. The practicalities and restrictions of CBDCs as a tool for development are covered [121]. Various central banks, such as the ECB, are already analyzing the issuance of CBDCs. The ECB's primary objective has been discussed intensively. The secondary objectives include the development of the Digital Euro as well as the energy sustainability of the bank [122].

Energy tokens, cryptocurrencies in general, and their sustainability features are also relevant fields of study, given that the technology they are using could be transposed to central bank digital currencies. In this context, research focuses on comparing traditional stocks with cryptocurrencies (like Ethereum or Bitcoin) and energy tokens from a return point of view. Once more is known about the features and design of CBDCs, specialists will be able to apply similar investment strategies to them, as in the case of stocks, and measure them using similar indicators. For example, cross-sectional uncertainty (CSU) can produce important returns when it comes to stocks if its predictability is measured correctly and can be used to forecast market excess returns [123]. In the future, it could be adapted to CBDCs and cryptocurrencies as well.

The findings suggest that energy tokens are less appealing as an investment option than stocks, commodities, or well-known cryptocurrencies and that those investing in them would do so for ecological reasons [124]. Another type of currency that could be used to promote sustainable development are social cryptocurrencies [125]. The energy consumption of blockchain technologies in general and Bitcoin in particular could also be reduced in order to promote green development through fiscal policies [126,128] and shortfalls regarding energy usage of cryptocurrencies need to be taken into account [129], together with the Environmental Performance Index (EPI) of cryptocurrency mining [127], reducing economic uncertainty with regard to CBDC [130].

There is a general consensus on the need to take the transition towards green finance into account when designing CBDCs. Even if only around 4 % of the articles focus on sustainability, the authors expect the trend to continue upward. China is a frontrunner in research around green finance in the context of carbon neutrality. In the context of the necessary reduction of carbon emissions worldwide, the energy transition must take place in the financial sector as well. Moreover, traditional central bank instruments need to be adapted to the digital economy and promote green development. Currencies using blockchain technology (such as Bitcoin) can be extremely energy-intensive, despite the fact that they ensure privacy. CBDCs will need to have a robust design both in terms of privacy and sustainability, and their issuers will need to find the delicate balance between these aspects while at the same time taking the citizens` best interests into account.

5. Conclusions and future research perspectives

A bibliometric analysis using VOSviewer, followed by a systematic literature review using PRISMA, has been performed in this article with the purpose of analyzing research around CBDCs, with a special focus on the sustainability aspects of blockchain, cryptocurrencies and CBDCs in general, thus adding value to the literature. The authors aimed to identify research trends in the field by studying positive and neutral research trends, as well as challenges. This comprehensive approach highlighted the implications of blockchain technology in general and cryptocurrencies and digital currencies in particular, ranging from economic, technological, legal, energy and green-related aspects. By extracting articles, together with their abstracts, from Scopus and the WoS, applying relevant inclusion and exclusion criteria to them, before inserting them into the PRISMA software and generating the relevant co-occurrence maps, it became clear that the topic will exponentially evolve in the future, as the topic of digital currencies is more relevant than ever.

Given that this topic is multifaceted (being affected by laws and regulations, policymakers, human behavior, the media, energetic aspects, the greening of the economy and more), that research does not put the same weight on all these aspects (some of which might have not yet been identified), and that the domain is ever-evolving, one of the limitations of the article lies in the fact that the authors might have excluded articles that are indirectly connected to digital currencies and still impact them. For example, the sustainable

Table 8
Future research topics: central bank digital currencies.

Central bank digital currencies	Technological considerations	• What technologies do citizens need to have access to in order to use CBDCs? • Are the existing technologies safe for use, or do they pose cybersecurity risks? • Can the existing technologies be easily and safely updated? • Are the existing technologies safer than the ones in place for traditional credit card payments?
	Sustainability aspects	• Is the energy used to generate CBDCs sustainable and clean? • Is the energy consumption related to the use of CBDCs higher than that of traditional payment methods? • Are CBDCs in line with sustainable goals 9 and 11? • Are CBDCs more sustainable in certain countries compared to others? (Countries in which energy costs less)
Central bank digital currencies	Inclusiveness	• Can all citizens get access to CBDCs, regardless of their socio-economic background and place of residence? • Are payments via CBDCs easy to make by citizens of all ages, regardless of their technological affinity?

development goal has an innovation aspect to it (promoting resilient infrastructure and innovation) that digital currencies need to take into account.

Another limitation lies in the fact that the authors only used VOSviewer and PRISMA to perform the analysis and did not use complementary software (such as Leximancer, for example) to dig deeper into the analysis. Such software might have offered additional insights. Moreover, the field is rapidly evolving and publications need several months to be published, meaning that some articles that have been analyzed are not in line with the latest trends anymore.

Looking forward, investigations into the impact of digital money and CBDCs on the economy as a whole and into ways to make them part of monetary policy could provide additional, interesting insights. Another area for future research would be the analysis of citizen perceptions regarding such currencies, together with the degree of possible acceptance depending on socio-economic factors such as age, income or even country of residence. Research still needs to be done in the areas of cybersecurity and safety of use surrounding CBDCs, as this can be an aspect that could influence citizens' behavior regarding the adoption of such currencies. The technology needed to use them is also a factor to be researched and taken into account, as not all citizens have access to smartphones. Another field for further research would relate to the implementation strategies of central bank digital currencies: would they be fully adopted and replace cash as we know it today or would they co-exist with traditional currencies and payment methods? These ideas for further research are summarized in Table 8.

Central bank digital currencies are an emerging and rapidly changing research topic and will almost surely shape tomorrow's society. This is why studying the literature on the topic is paramount, as it can give directions for further research as well as help understand the current state of research better, allowing researchers to build on it.

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Data availability statement

The data will be made available upon request from the corresponding author.

CRediT authorship contribution statement

Silvana Prodan: Writing – review & editing, Supervision, Software, Project administration, Funding acquisition, Data curation. **Peter Konhäusner:** Writing – original draft, Resources, Investigation, Formal analysis, Data curation, Conceptualization. **Dan-Cristian Dabija:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Formal analysis. **George Lazaroiu:** Writing – original draft, Visualization, Supervision, Project administration, Methodology, Data curation. **Leonardo Marincean:** Writing – review & editing, Validation, Resources, Investigation, Funding acquisition, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e30561.

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