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Digital Treasure Hunt: Discovering Central Bank Digital Currencies

Master's Thesis (30 ECTS)

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Tartu 2024

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Abstract:

Central Bank Digital Currencies (CBDCs) represent a significant shift in the financial landscape, merging traditional banking with digital technology. As central banks explore CBDCs, understanding their foundational aspects is crucial. CBDCs, issued and regulated by central banks, enhance financial inclusion, increase payment efficiency, maintain monetary sovereignty, and improve cross-border transactions. This study comprehensively examines these motivations, technical designs, challenges, and impacts. This study demonstrates that while CBDCs offer significant benefits, they also pose technological, financial, societal, and legal challenges. The paper's detailed analysis, including a table of current CBDC projects, provides valuable insights for future research and implementation. These findings are vital for central banks, policymakers, technologists, economists, and researchers in the evolving landscape of digital currencies.

Keywords:

Central Bank Digital Currency, CBDC, digital currencies, FinTech

CERCS: P170 Computer science, numerical analysis, systems, control

Digitaalne Aaretejaht: Keskpankade Digitaalvaluutade Avastamine

Lühikokkuvõte:

Keskpankade digitaalsed vääringud (CBDC) kujutavad endast olulist muutust finantsmaastikul, ühendades traditsioonilise panganduse ja digitaaltehnoloogia. Kuna keskpangad uurivad CBDCd, on oluline mõista nende põhiaspekte. Keskpankade poolt emiteeritud ja reguleeritud CBDCd suurendavad rahalist kaasatust, suurendavad maksete tõhusust, säilitavad rahalise suveräänsuse ja parandavad piiriüleseid tehinguid. Käesolevas uuringus uuritakse põhjalikult neid motive, tehnilisi lahendusi, probleeme ja mõju. Uuring näitab, et kuigi keskpangad pakuvad märkimisväärset kasu, tekitavad nad ka tehnoloogilisi, finantsilisi, ühiskondlikke ja õiguslikke probleeme. Dokumendi üksikasjalik analüüs, sealhulgas tabel praegustest CBDC-projektidest, annab väärtuslikke teadmisi tulevaste uuringute ja rakendamise kohta. Need järeldused on olulised keskpankadele, poliitikakujundajatele, tehnoloogidele, majandusteadlastele ja teadlastele digitaalsete valuutade areneval maastikul.

Võtmesõnad:

Keskpanga Digitaalne Valuuta, CBDC, digitaalsed valuutad, FinTech

CERCS: P170 Arvutiteadus, arvutusmeetodid, süsteemid, juhtimine (automaatjuhtimisteooria)

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1 Introduction

Over time, there has been numerous changes regarding what is considered as money, what is its purpose [12]. These changes aroused due to the progress in the economies and payment systems [12]. Initially, money was defined as commodity [12]. After some time, metal coins such as bronze, silver, and gold were used as money [12]. Later, paper money was introduced [12]. The latest form of the money is in digital form [12]. Notably, the ongoing century can be characterized by rapid digitalization of the economic structure [9]. Over time, money and its institutional foundations have grown, and the growth has brought innovations and infrastructural changes that have progressed simultaneously with the advancements in technology [9]. The way people are interacting with the payment options is affected by the ongoing digitalization of the economy [9].

In 2009, when Bitcoin was launched it set the preliminary stage for the future of digital currencies [13]. Particularly, introduction of bitcoin kickstarted the evolution of digital currencies in three paths - cryptocurrencies, stable coins, and Central Bank Digital Currency (CBDC) [13]. Cryptocurrencies are considered to be a modern iteration of virtual currencies and can be traded using real currencies as well as other cryptocurrencies based on their exchange rates [5]. Cryptocurrencies are issued privately and do not have the backing of central banks [10]. For the most part, due to sharp and common fluctuations in their values, they are considered to be highly volatile to be considered a viable store of value. Stablecoins aim to overcome the erratic nature of cryptocurrencies, such as the Bitcoin, by providing a stable value via some form of backing [10]. For example, Tether is a cryptocurrency that has its value pegged to a US Dollar [8]. However, in some cases, stablecoins may lose their peg and crash. This case was observed with Terra project's stablecoin TerraUSD (UST), which despite being pegged to US Dollar, lost its peg in May of 2022 and crashed [8]. With their launch and Bitcoin's ideology, cryptocurrencies emerged as a threat to the central banks and the current structure of the global monetary system [7]. Subsequently, central banks and public institutions started voicing their concerns about the risks posed by the cryptocurrencies and their disruptive potential to the existing monetary policy tools [7]. Nowadays, however, central banks have assumed a more favorable position regarding digital currencies, while simultaneously adopting a more fierce attitude towards cryptocurrencies [7]. Consequently, in the recent years, numerous central banks globally have launched research projects and commenced developing their own digital asset, the CBDC [7].

CBDC is a digital form of the banknote currency, created and backed by a country's central bank [10]. Implementation of a CBDC necessitates the establishment of a completely novel infrastructure by the central bank to enable digital payments via CBDC [10]. While at some scale, CBDC, cryptocurrencies and stablecoins are related, the focus of this study revolves solely around CBDC.

DLT and digital currencies are closely correlated each other as the former was

found as the underlying technology for the cryptocurrency Bitcoin [3]. However, while cryptocurrencies went under the radar for a while, as the market capitalization and price of the Bitcoin surged dramatically [7]. As a consequence of its rapid growth, blockchain and DLTs has gathered a strong interest from financial entities, governments, high-tech institutions and the capital markets [4][6]. While the origins of the DLTs stem from anti-authority ideologies, they can also be utilized for the creation of digital fiat currencies distributed by the central banks [4]. Initially, some central banks were against the idea of digital fiat currencies. However, the rapid rise of cryptocurrencies alongside the development of decentralized finance (DeFi) applications across a range of fields of the financial system has since prompted the banks to change their initial stance [7][8].

Statistically speaking, while only 35 countries were contemplating CBDC in May 2020, today over 114 countries, which accounts for more than 95% of the global GDP, are experimenting with it [9]. While the CBDCs are popular among the central banks, the banks are taking different approaches, with different technological implementation. For example, while developing economies such as mainland China, Cambodia, and Bahamas are inclined towards implementing Residential CBDC, developed economies such as Japan, Honk Kong, Canada, and Singapore are gravitating towards wholesale CBDC [13].

At present, there seems to be a lack of overview into the motivation of banks pursuing CBDC, different approaches to building a central digital currency, and its advantages and disadvantages. Furthermore, the research also seems to be superficial in areas related to the potential impacts of CBDC as well as challenges associated with it.

Given the strong interest of the countries around the globe towards CBDC and limited availability of the research around the topic, several research questions need to be investigated. This paper aims to answer several questions regarding CBDC to better explore the area. Specifically, the study claims that it is vital to analyze what motivates the banks and countries to become involved and start experimenting with CBDC. Secondly, considering the central banks are central entities as the name implies, while DLTs and Blockchain technology based upon the idea of absence of a central governing figure, it is needed to analyze how CBDC, the idea that gained attraction only as a byproduct of the rise of the blockchain based implementations, could be implemented, and what would be the technical as well as societal challenges and risks associated with each implementation technique. Finally, it is vital to understand what changes CBDC will bring upon the current monetary policy, and what will be its impact. Given the uncertainty surrounding the mentioned topics, the main aim of this paper is to analyze and build upon the existing white and gray literature and explore an answer the following research questions:

- RQ1: What are the driving forces motivating central banks and governments explore CBDC?
- RQ2: What possible technical ways of implementing a CBDC exist?

- RQ3: What challenges are associated with CBDC?
- RQ4: What is the expected impact of CBDCs?

To accomplish the research objectives, the outlined research questions in the paper were addressed using a variation of Systematic Literature Review (SLR) technique referred to as Multivocal Literature Review (MLR). This research will be of a significant contribution to the literature in the topic of CBDC, notably why banks are pursuing it, and how it could be implemented by different central banks, challenges associated with CBDC and its expected impact. Another contribution of the paper is a table demonstrating the existing state of CBDC, which is a reference for future researchers aiming to come up with further research in the area. Therefore, the contribution of the research will be of use for banks that are seeking different ways of implementing CBDCs as well as future researches who want to explore different CBDCs in detail.

The paper is organized in the following way. Section 2 delves into the topics needed to understand the research. Section 3 goes over the existing literature and talks about where this paper falls into in relation to the prior research. Section 4 explains the utilized methodology to achieve the findings. Section 5 summarises and explores the results of the research. Section 6 discusses the findings found in the prior section. Section 7 talks about the limitations of the thesis. Section 8 presents recommendations regarding what could the future studies explore. Section 9 provides concluding remarks.

2 Background

The section gives a brief overview of the terms and concepts involved with in centralized and decentralized finance. Topics explained in this section are prerequisites to understanding the subsequent sections of the thesis as the further sections will assume that the reader is already informed on the topics mentioned in this section.

2.1 Distributed Ledger Technology (DLT)

A decentralized, permissionless, distributed database in which every participating node keeps its own copy of the distributed ledger. A crucial innovative point of the DLTs in the space of digital currencies is that it provides a cryptographic mechanism for ensuring security and protecting system integrity in a decentralized ledger. The ledger is managed by a network of anonymous participants without requiring for trust from one or more entities [3]. Using the peer-to-peer communication model, the participants are sharing the records in the distributed ledger across the network with each other. Through this, a replica of the database is maintained across the nodes which eliminates the need for a reliance on a single party or intermediary for the operations [11]. While DLT was originally designed as a solution to support cryptocurrencies, it has attracted popularity from wide range of fields in the industry [3]. These industrial applications include supply chain, education, healthcare, education, finance, transport, and governance [3].

2.1.1 Blockchain

A technology based on the design of distributed ledger is the blockchain [3]. At its core, Blockchain is comprised of three major pieces of technology: cryptography, peer-to-peer protocols, and data storage [2]. Blockchain is a type of database for maintaining a ledger of all transactions in a distributed system where the collaborating parties are considered to be non-trusting [1]. In more elaborative terms, blockchain is a specific type of data structure utilized in some distributed ledgers, designed to store and transmit data in units known as ‘blocks’. These blocks are digitally linked together in a sequence or ‘chain’. Blockchain technology employs cryptographic techniques and algorithms to ensure data is recorded and synchronized across a network in an immutable and secure manner [3]. There are different types of blockchains out there. For example, perhaps the most prominent one, is the Bitcoin. The Bitcoin Blockchain was created to counter the problem of double spending of digital money [2]. Paragraphs below discuss blockchains related to this paper.

Ethereum Launched in 2015, Ethereum is an open-source, public blockchain platform designed for creating decentralized applications. Initially, Ethereum operated as a public permissionless blockchain utilizing a Proof-of-Work (PoW) consensus protocol known as

Ethash. It also offers the option to be configured as a private platform. Due to the security limitations and high computational demands of PoW, some Ethereum testnets have begun adopting the Clique Proof-of-Authority (PoA) consensus protocol. In PoA, blocks are validated by a set of approved signers, making the process less resource-intensive compared to Ethash's mining. The list of signers in Clique is flexible, allowing signers to propose and vote on the addition or removal of other signers, with changes implemented based on majority votes. Furthermore, Ethereum supports smart contracts, which are written in the Solidity programming language, for executing decentralized applications (Dapps). The Ethereum Virtual Machine (EVM) is another key feature, allowing any node to execute programs written in any programming language. Ethereum also has its own native cryptocurrency, Ether [77].

R3 Corda R3 Corda is an open-source, permissioned platform created by R3. Adhering to the “Know Your Customer” principle, each node must verify its identity to gain authorization to join the network. The Doorman node is responsible for validating identities and issuing certificates. The network also includes one or more Notary nodes, which ensure the uniqueness and proper sequencing of transactions without the need for global broadcasting. Corda requires two types of consensus: validity and uniqueness. Validity is verified by each signer before they sign the transaction, while uniqueness is ensured by the Notaries. Corda supports smart contracts written in JVM languages and facilitates the development of decentralized applications (CorDapps) using Kotlin [77].

Hyperledger Fabric Hyperledger Fabric, a project under the Hyperledger umbrella managed by the Linux Foundation, functions as a decentralized operating system for permissioned blockchains and supports the execution of distributed applications (Dapps) developed in general-purpose programming languages like Go, Java, or Node.js. A Fabric network consists of nodes with identities managed by a membership service provider. These nodes can serve different roles: clients propose transactions for execution and broadcast them for ordering, peers maintain the ledger and its state, and ordering service nodes determine the sequence of all transactions without engaging in transaction execution or validation. Fabric utilizes smart contracts, referred to as chaincodes, to implement application logic. The platform includes the Solo consensus protocol by default, a voting-based system where endorsing nodes, a subset of peers, execute and validate transactions according to the endorsement policy. Moreover, Fabric is flexible, allowing the integration of other consensus protocols such as Practical Byzantine Fault Tolerance (PBFT), Raft, or Kafka for using multiple ordering nodes. Notably, Fabric does not have an inherent cryptocurrency [77]

Quorum Quorum, created by J.P. Morgan for financial use cases, is also applicable across various industries. It is a permissioned blockchain that builds on the Ethereum

blockchain, specifically as a fork of go-ethereum. Quorum offers several notable improvements. For privacy, it allows the creation of private contracts and transactions, with the transaction payload visible only to designated participants, while public transactions remain possible within the permissioned network but are not exposed to the public Ethereum blockchain. It includes additional consensus protocols suitable for consortium blockchains, such as a Raft-based protocol and Istanbul BFT. Quorum's permissioning ensures that only authorized and known peers, defined through smart contracts, can join the network. Furthermore, Quorum is designed for enhanced performance compared to the standard Ethereum blockchain [77].

2.2 Consensus algorithms

2.2.1 Proof-of-Work (PoW)

Proof of Work (PoW) is the most widely used consensus mechanism, employed by popular cryptocurrencies such as Bitcoin and Litecoin. In this process, known as mining, participating nodes, referred to as miners, work to solve complex mathematical problems and puzzles. This requires substantial computational power and processing time. The first miner to solve the puzzle and create a new block is rewarded with cryptocurrency [79].

2.2.2 Proof-of-Stake (PoS)

Proof of Stake (PoS) is the second most common consensus mechanism, serving as an alternative to Proof of Work (PoW). PoS is more energy-efficient, requires less processing time, incurs lower costs, and demands less computational power compared to PoW. In PoS, a randomized method is used to determine which participant gets to create the next block in the blockchain. Instead of miners, PoS employs validators. Users can become validators by staking their tokens, which involves locking up their tokens for a certain period to be eligible to create a new block. The user with the largest stake has the highest likelihood of being selected as a validator, with the selection also influenced by the duration their tokens have been staked. This method conserves energy, as only the chosen validators participate in block creation. PoS is highly effective because if a validator acts maliciously, they forfeit their staked tokens. Honest validators are rewarded, while those who verify and validate the block receive transaction fees instead of block rewards, unlike in PoW. This consensus mechanism is notably used on the Ethereum platform [79].

2.2.3 Proof-of-Authority (PoA)

Proof of Authority (PoA) is a family of consensus algorithms designed for permissioned blockchains, known for their improved performance compared to typical Byzantine Fault

Tolerance (BFT) algorithms due to more efficient message exchanges. Originally proposed within the Ethereum ecosystem for private networks, PoA has been implemented in clients like Aura and Clique. PoA algorithms depend on a set of trusted nodes known as authorities, each uniquely identified and with at least a majority ($N/2 + 1$) assumed to be honest. These authorities reach consensus to order transactions issued by clients. The consensus mechanism in PoA involves a mining rotation scheme, which distributes the responsibility of block creation fairly among the authorities. Time is divided into intervals, and in each interval, one authority is designated as the mining leader [80].

2.2.4 Practical Byzantine Fault Tolerance (PBFT)

Practical Byzantine Fault Tolerance (PBFT) is a type of state machine replication. The set of replicas is denoted by Q , and each replica is identified by an integer in the range $\{0, 1, \dots, |Q| - 1\}$. PBFT can tolerate up to f invalid or malicious replicas. To function correctly, the system requires at least $2f + 1$ functioning replicas, meaning that the total number of replicas $|Q|$ must be at least $3f + 1$. This implies that PBFT can handle no more than one-third of the replicas being faulty or malicious. The primary replica (replica 0) is responsible for view changes, ensuring $p = v$, where v is the current view number. The algorithm comprises three components: the three-phase consensus protocol, the view change protocol, and the checkpoint mechanism. The three phases in the consensus protocol are pre-prepare, prepare, and commit [81].

During the pre-prepare phase, the primary replica assigns a sequence number n to the request, multicasts a pre-prepare message to all backup replicas, and logs the message [81].

If a backup replica accepts the pre-prepare message, it transitions to the prepare phase by multicasting a prepare message to all other replicas and logging both messages. If it does not accept the pre-prepare message, it takes no action. A replica (including the primary) will accept prepare messages if their signatures are valid [81].

Once a replica has accepted $2f + 1$ prepare messages, it multicasts a commit message to the other replicas, initiating the commit phase. Replicas then accept commit messages, provided they are properly signed, and insert them into their log [81].

2.2.5 QuorumChain

The QuorumChain Consensus algorithm uses a majority-based voting system to achieve consensus. This algorithm operates through a smart contract that keeps track of votes and eligible voter nodes. When a potential new block is discovered, voting nodes cast their votes on whether to accept the block. For the block to be added to the blockchain, it must receive the majority of votes and surpass a specific threshold number of votes. This mechanism helps prevent the addition of multiple blocks containing the same transactions. To further reduce the chance of multiple miner nodes creating identical

blocks simultaneously, the algorithm includes timeout sessions, which are pseudo-random intervals that must pass before a miner node is allowed to create a block [78].

2.3 Central Bank Digital Currency (CBDC)

A type of virtual money that is tied to a country's official unit of currency and is under the direct control of the central banks. This means that the central banks are in charge of the issuance and management of the digital currencies. [7]. Like cash, a CBDC is denominated to a currency such as Dollar, Euro, Lira, Yen or any other country's currency. In other words, 10, 50, or 100 monetary amount of a CBDC would be equivalent to its banknote form [10]. For example, e-CNY is the digital version of the fiat currency Chinese Yuan issued by the People's Bank of China [8]. What makes CBDC different from other digital currencies such as the Bitcoin or any other crypto asset, is that unlike crypto assets that are a privately issued, CBDC is a central bank issued and backed currency [10].

3 Related work

This section provides an overview of related work discussing CBDCs, encompassing various facets such as motivations, technical implementations, challenges, and implications. By examining a range of studies from different perspectives, the aim is to highlight the multifaceted nature of CBDC research. This comprehensive review sets the stage for understanding the broader landscape and identifying the existing research gaps that this study aims to fill.

Singh et al. [45] explore the motivations for launching CBDCs in emerging markets. The study responds to the rise of private digital currencies like cryptocurrencies and stablecoins by examining why central banks are considering digital versions of their fiat currencies. Through a literature survey and qualitative expert interviews, the researchers identify four major and 13 sub-categories of motivations. They use a fuzzy analytical hierarchical process to determine the relative importance of these motivations. The findings reveal that payment-related motivations are the most significant, with financial inclusion and payment efficiencies being the dominant sub-criteria, highlighting the key drivers for global interest in sovereign digital currencies.

Opare and Kim [17] discuss CBDCs from the perspective of distributed ledger technology (DLT) experiments conducted by central banks worldwide. Their comprehensive survey compiles publicly available DLT-based CBDC experiments with completed proof-of-concept prototypes, providing insights into the motivations and best practice approaches for these initiatives. They classify and propose a generic framework for CBDCs, highlighting the limitations and use cases of existing DLT platforms in the financial services industry. The survey serves as a critical reference for central banks, monetary authorities, and researchers, focusing on the technical feasibility and challenges of using DLT to issue CBDCs.

Ozili and Náñez Alonso [53] investigate the factors limiting the adoption of CBDCs and propose possible solutions. They also assess media sentiment about CBDCs in general and locally issued CBDCs. The study finds a high correlation between negative media sentiment about CBDCs in general and locally issued CBDCs, such as the eNaira, DCash, and Sand Dollar. Interestingly, while negative media sentiment about these specific CBDCs was influenced by the overall negative sentiment towards CBDCs, positive media sentiment about these currencies was not similarly affected by the general positive sentiment towards CBDCs. This highlights the significant role of media perception in the challenges facing CBDC adoption.

Luu, Nguyen, and Nasir [49] analyze the implications of CBDC adoption on financial stability, particularly within the banking sector. Utilizing data from 1176 banks across 86 countries between 2010 and 2021, they construct a time-varying CBDC adoption index. Their findings indicate that CBDC adoption enhances financial stability, with positive contributions from factors such as bank size, capitalization, operational strategy,

deposit funding, and domestic investment. Conversely, loan loss reserves negatively impact stability. The study also reveals that CBDC adoption reduces leverage and asset risks, improves asset quality, and expands lending. The effects are more pronounced in larger banks and emerging economies. Retail CBDCs promote stability, while wholesale CBDCs may have the opposite effect. These insights underscore the significant role of CBDCs in financial stability and provide important considerations for their adoption.

While the existing literature has explored various aspects of CBDCs, such as motivations, technical implementations, challenges, and implications, these studies have often been limited in scope. Many have focused on specific regions, countries, or economic systems, particular implementation models, or the impact of CBDCs within specific sectors like finance. Consequently, there is a notable research gap in providing a comprehensive and generalized overview of the CBDC landscape. This study aims to address this gap by synthesizing and consolidating existing research to offer a holistic introduction to the field of CBDCs, transcending specific contexts and delving into the broader implications and potential of this emerging financial technology.

4 Methodology

In order to come up with conclusive findings to the proposed research questions, Multivocal Literature Review (MLR) method is used. MLR is a variation of SLR which includes both academic and gray literature [14]. MLR research technique that involves identifying, assessing, and utilizing the existing literature to explore a topic, hence, making a new contribution to the field.

To this aim, existing literature from peer-reviewed journals are collected. However, the scope of CBDC extends beyond the scientific literature and more practical applications could be found from other sources. Therefore, for this study data from the gray literature is used in conjunction to the scientific literature. Particularly, gray literature involving government reports as well as publishing from audit companies, banks, and other financial institutions are used as a part of the MLR. The inclusion of such papers provides a perspective more aligned with the real world environment and shed a light on topics otherwise missed by the scientific literature. Furthermore, using gray literature in addition to academic papers is more conducive in answering our research questions as data coming from the central banks or the governments is bound to be more aligned with their stance on CBDC.

Figure 1 demonstrates the steps involved in MLR.

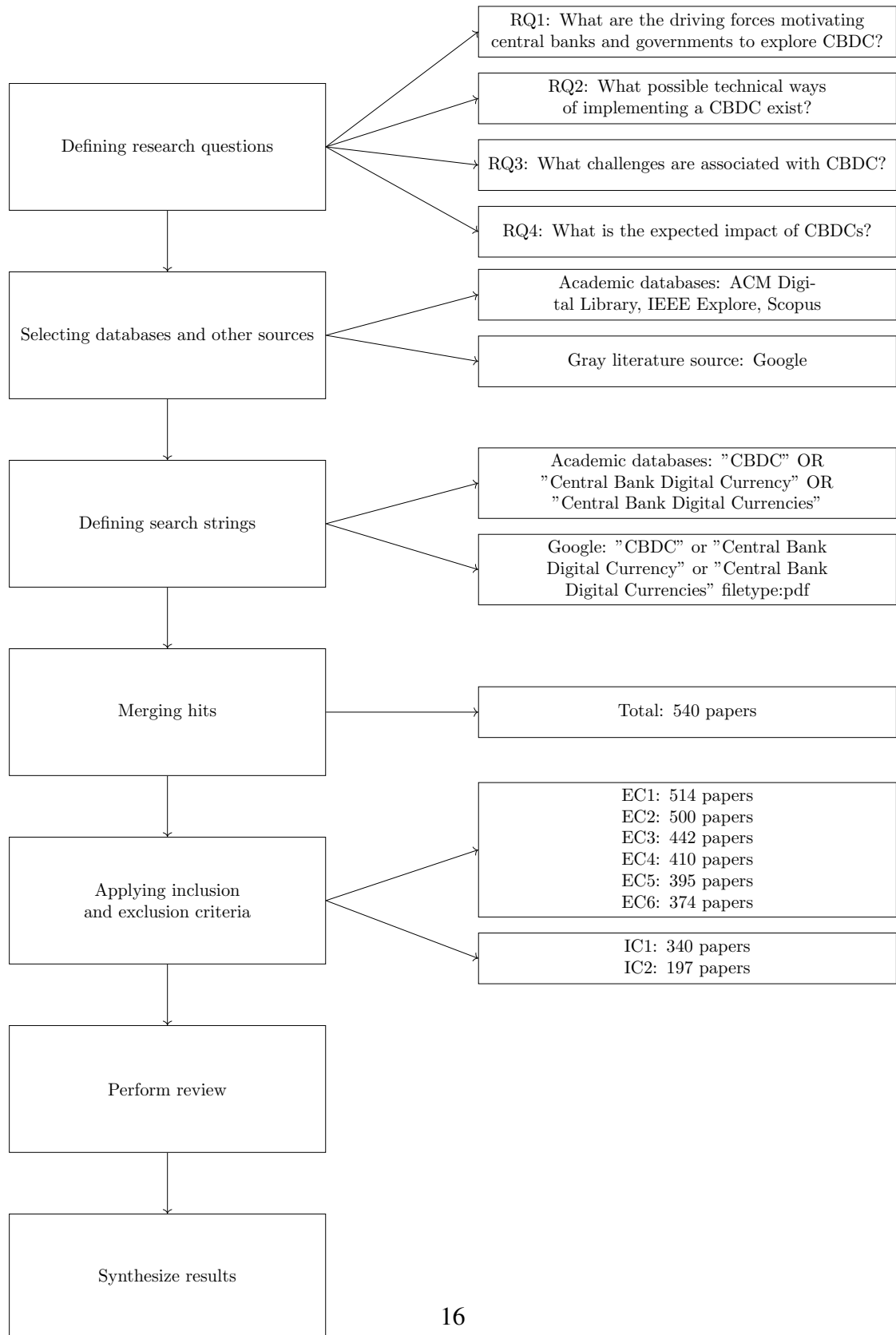


Figure 1. MLR Steps

4.1 Preparation stage

First step in the methodology is the preparation stage. Initially, the section introduces the research questions, and gives a brief overview of each question. Thereafter, the keywords are come up with and discussed, and reasoning behind choosing them is given. Then, the search string for data exploration is introduced and explained. The section also includes the sources that are used in data collection. Subsequently, the inclusion and exclusion criteria are analyzed and presented.

Moreover, in this stage the main topics and points of discussions of the existing literature are assessed. Following this step, the current state of the research is analyzed and gaps in the research are identified. Consequently, the scope of the study is formed and the research questions of the paper are devised.

4.1.1 Research questions

Following the analysis of the existing material, the following research questions are formulated.

RQ1: What are the driving forces motivating central banks and governments explore CBDC? While the previous papers have outlined the driving force behind the pursuit of CBDCs by financial organizations and governments, there is no clear answer and each paper gives their own reasoning. This paper aims to identify reasons mentioned in the sources and rank them by their commonness. This research question provides a crucial perspective on why the governments are considering CBDC adoption on a national level.

RQ2: What possible technical ways of implementing a CBDC exist? Existing literature outlines several ways of CBDC implementations. As a part of the research question, this paper aims to analyze and contrast the existing technical design choices involved in implementing a CBDC. To make it clear, the paper does not introduce a novel way implementing it, nor does it discuss a potential way of implementing a CBDC. It focuses solely on the existing approaches utilized by the banks. The paper does this by looking at existing CBDC projects as well as CBDC projects that are being worked on by the central banks.

RQ3: What challenges are associated with CBDC? Creating an entirely new form of money is susceptible to bringing along challenges with itself. These challenges can be of different natures such as economical, macro-economical, anonymity, technical, criminal, and other categories. While it is possible to find literature that discusses these challenges separately, this paper aims to collect the existing information, then group the findings under a common research question.

RQ4: What is the expected impact of CBDCs? The objective of the question is to assess the influence and examine what potential changes CBDCs will bring about. The question aims to find out how currently established economic order, monetary policy, taxation, interest rates, and other related factors will be affected by the introduction

of CBDC. This paper will differ from the existing literature by bringing together and analyzing which areas are likely to be the most affected and in what ways from the existing literature.

4.1.2 Data collection

To ensure that the data used for the MLR is relevant when collecting the papers and reports, the relevant terms regarding the topic were identified. Furthermore, plural versions and abbreviations are considered as well to ensure that the data at hand is complete. Consequently, the following terms are considered:

1. "Central Bank Digital Currency" - the term is the key term of this research and is the topic upon which the paper is based around.
2. "Central Bank Digital Currencies" - some papers and reports use plural version of the noun.
3. "CBDC" - abbreviation for Central Bank Digital Currency.

Utilizing the keywords a single search query is constructed to apply in the academic and gray literature databases:

"CBDC" OR "Central Bank Digital Currency" OR "Central Bank Digital Currencies"

The same search string is also utilized for querying the gray literature as well. However, in order to filter out websites, an additional option is added to preserve only PDF material, by appending *filetype:pdf* to the end of the search string in Google. As a result, the following query is used for the Google search:

*"CBDC" or "Central Bank Digital Currency" or "Central Bank Digital Currencies"
filetype:pdf*

The data collection is done from two source types - academic and gray literature. For collecting the academic literature ACM Digital Library, IEEE Xplore, and Scopus are used. Furthermore, certain papers are added through backwards referencing. Backwards referencing was conducted by following the guidelines outlined by Claes Wohlin in the paper Guidelines for Snowballing in Systematic Literature Studies and a Replication in Software Engineering [15].

The gray literature on the other hand is queried from Google (<https://google.com>) using advanced search settings. One important point is that, in order to filter out the low quality reports as well as have a high degree of trust in the reports, the used gray literature is only gathered through reports from official financial organizations such as audit companies, payment service providers, central banks, political and economic unions

such as the European Union, and governments and their branches. Some papers are added through backwards referencing. To conduct this Multivocal Literature Review, the guidelines outlined in "Guidelines for including gray literature and conducting multivocal literature reviews in software engineering" by Garousi et al. [14] will be followed.

Table 1 shows the number of hits from each data source.

Source	The number of papers
ACM Digital Library	22
IEEE Xplore	42
Gray literature	169
Scopus	309
Total	540

Table 1. The total number of academic papers from each source

4.1.3 Study selection and quality assessment

To narrow down the number of results, exclude irrelevant studies as well as to have a more up-to-date data the following exclusion criteria are used. Firstly, given that the vast majority of the countries started delving into CBDC realm starting from 2020, papers and reports prior to the year of 2020 are excluded. Secondly, data that is not in English is factored out as well. This is done for two reasons. First, out of all the languages that papers and reports have been published in, the author of the paper is more proficient with the English language. Secondly, the majority of the existing research is available in English, henceforth, papers and reports in English alone are deemed to provide satisfactory amount of data for addressing the research questions in a quality manner. In the following step, types of publications are limited to research papers, conference papers, and book chapters for scientific literature, and reports. To this end, publications or reports of type opinion, note, abstract, books, review, survey, poster, and work-in-progress are removed from the result set. Moreover, papers that cannot be accessed are excluded from the set of papers. Another criteria that is used to rule out the data is regarding the length of the content. Specifically, papers shorter than 4 pages in terms of content are excluded from the pool. It is improbable for reports and papers fewer than 4 pages to provide comprehensive data or context in relation to the subjects relevant to the research questions. Therefore, they are unlikely to describe content related to the research questions at a comprehensive level. It should be specifically mentioned that, this count is not about the total count of the pages in a given document but rather it refers to the number of pages with actual content in it. In other words, if the total number of pages is more than 4, however, when reference and appendix sections are excluded, the number of pages drops below 4, then that paper is excluded. In the final step, duplicate

papers are eliminated. In the context of this paper, there are two types of duplicates. First type encompasses the papers originally published as a conference paper, then extended to a journal paper. In these cases, the conference publication versions are excluded, and instead only journal version of the paper is considered. Second type is when the same paper appears in two different databases, in such cases, only a single instance of the paper is included as a part of the MLR data.

With these in mind, to eliminate the papers the following 4 exclusion criteria are used:

- EC1: Papers published before 2020.
- EC2: Papers and reports not in English.
- EC3: Publication or report is either opinion, note, review, poster, book, work-in-progress or survey.
- EC4: Paper or report is not accessible.
- EC5: Papers shorter than 4 pages.
- EC6: Duplicate papers.

Additionally, 4 inclusion criteria are formulated to ensure that relevant papers remain for the MLR process. To ensure that CBDC constitutes essence of a given paper, papers that have "CBDC", "Central Bank Digital Currency", or "Central Bank Digital Currencies" among the keywords and abstract are included. On the basis of this notion, the first two inclusion criteria are formed. Third criteria is that CBDC is the main topic of the paper or a report. This is to ensure that the papers and reports that cover CBDC superficially are not included as a part of the MLR. The final criteria is regarding the relation between the research questions and a given paper's content. Only papers that are related to at least one of the research questions are included. In other words, if a paper discusses CBDC thoroughly but fails to address at the very least one of the research questions in a substantial way, then that paper or report is not included in the literature review. As a result, the following inclusion criteria are used for the data exploration:

- IC1: CBDC is the main topic of paper or report.
- IC2: Paper or report discusses CBDC from the perspective of at least one of the research questions.

4.2 Execution stage

Following the preparation stage, the process of applying the exclusion and inclusion criteria to the overall data obtained from the previous stage commences.

Initially, exclusion criteria are applied in a sequential way. Following that, the papers are included on the basis of the inclusion criteria which are also enacted in an orderly fashion.

Table 2 demonstrates the progress of applying exclusion and inclusion criteria, showing the number of papers remaining after each step.

Filter	Papers remaining
Initial count	540
EC1	514
EC2	500
EC3	442
EC4	410
EC5	395
EC6	374
IC1	340
IC2	197

Table 2. The result of each exclusion and inclusion criteria

5 MLR results

In this section, the results of the MLR are presented. Each research question is discussed in a separate subsection. The subsections follow the same order as the research questions in section 4.1.1.

5.1 Motivations and objectives behind CBDC initiatives

The review identified 5 primary motivation factors that push the governments towards CBDC exploration. These include, financial inclusion, money digitalization, monetary sovereignty and financial stability, cross-Border transactions, the bandwagon effect, and national security. The following subsections discuss each motivation in detail. The subsections ordered in descending order based on the amount of data found for each motivation category.

5.1.1 Financial inclusion

Financial inclusion has remained a critical macroeconomic issue in emerging markets. Therefore, payment efficiency and financial inclusion are primary motivations for launching CBDCs in these regions [30]. While the EU and North America have achieved high degrees of financial inclusion, leading to limited impact from CBDC introduction, many other countries with less developed economies and financial infrastructures stand to benefit from CBDC implementation [43]. In developing economies, financial institutions are often inaccessible due to barriers such as formal identification requirements, minimum deposit and balance mandates, and the need for a local bank branch [37]. Commercial banks frequently find it unprofitable to serve poor people and small businesses in remote and marginalized regions [37]. Several emerging countries see CBDCs as an opportunity to strengthen financial inclusion [30]. By using CBDCs, these countries aim to capture transaction data from the sizable informal economy and enhance financial inclusion [25]. For small businesses in remote areas and poor people deprived of financial services, token or account-based CBDCs could serve as a gateway to financial products and services [30].

For example, the outcomes of the e-peso pilot project in Uruguay demonstrated that the introduction of CBDCs can promote financial inclusion through the formalization of the shadow economy [30]. CBDCs can reduce costs by eliminating intermediaries and promoting faster clearing and settlement [30]. Despite the presence of marginalized populations and small businesses in remote areas that still lack financial services, most of these people own mobile phones, providing a potential pathway for financial inclusion through digital means [30]. Another instance is the Sand Dollar in the Bahamas, which was introduced to enhance payment services within the country's scattered archipelago [39].

5.1.2 Money digitalization

The advancement of financial markets and the shift towards cashless transactions are key drivers behind the adoption of CBDCs in developed nations [25]. The reduction in cash usage and the increase in digital financial solutions that bypass traditional banking systems challenge central banks' exclusive right to issue money [43]. For example, the rise of stablecoins and financial platforms like Wise operate independently of traditional banking systems and create alternative methods for storing and transferring value. Additionally, concerns about the dominance of major foreign payment service providers such as Visa and Alipay, in national markets have further incentivized central banks [43]. The growth of Big Tech companies into financial services introduces new systemic risks and competitive pressures [43]. These firms are expanding their financial offerings and considering the issuance of their own stablecoins [43]. For instance, Facebook's initial Libra project (later renamed Diem) showcased significant market interest in digital currencies [43]. Although this project was eventually abandoned, it underscored the potential demand for central bank-issued digital currencies [43]. Consequently, numerous central banks are now prioritizing the issuance of CBDCs to curb the widespread use of risky stablecoins in an evolving digital environment [43].

For example, China's e-CNY initiative aims to address the threats posed by cryptocurrencies like Libra/Diem [33]. Officials at the People's Bank of China (PBOC) have indicated that the e-CNY is intended to mitigate these threats [33]. Similarly, India introduced the Digital Rupee to protect the public from the volatility of the crypto market and to improve the functioning of existing payment systems [18].

5.1.3 Monetary sovereignty and financial stability

Monetary strategic autonomy refers to a central bank's ability to pursue national interests and implement preferred monetary policies without dependence on foreign financial institutions or infrastructures [43]. The launch of retail CBDCs in developed countries primarily aims to improve the efficiency and security of domestic payments and ensure financial stability [16]. Additionally, as a byproduct of money digitalization and foreign CBDCs, domestic fiat currency could come under the threat of substitution, resulting in a loss of control over monetary affairs [30]. Consequently, to protect monetary sovereignty, central banks are introducing government-backed digital currencies [30].

CBDCs can provide central banks with more effective monetary tools, leading to increased confidence in the monetary system, improved payment efficiency, decreased transaction costs, and reduced risks of systemic manipulation and illicit practices, ultimately resulting in better financial stability [65]. As cash usage declines, central banks face challenges in influencing monetary processes, underscoring the need for CBDC implementation [49]. CBDCs can be leveraged to manage the money supply and directly and effectively impact interest rates [49]. By issuing CBDCs, central banks can com-

plement cash as public money, ensure the continued availability of a risk-free medium of exchange, and maintain payment efficiency in an increasingly electronic payment landscape [68]. Therefore, introducing CBDCs provides central banks with a significant advantage in implementing monetary policy [49]. For example, in adverse economic periods, reserve banks want to push for lower interest rates to encourage consumer spending [30]. Especially in dire economic circumstances, central banks have to experiment with negative short-term interest rates [30]. Since cash always offers a zero nominal interest rate, central banks face a major constraint in imposing negative interest rates [30]. Central banks can effectively impose negative nominal interest rates through the complete replacement of cash with digital fiat currency [30]. Additionally, CBDCs also add potency to monetary policy in good economic conditions [30]. An interest-bearing CBDC, for example, can incentivize consumers to save rather than invest or consume [30]. Furthermore, during crisis periods CBDC can also facilitate helicopter drops¹ [30].

Moreover, in economies nearing cashless status due to high digital payment maturity, maintaining public access to central bank money becomes a significant concern [63]. For instance, Sweden's central bank, the Riksbank, is developing the e-krona in response to declining cash use, aiming to guarantee public access to central bank money and limit dependence on intermediary institutions for transmitting monetary or fiscal policy, particularly in the context of zero or negative interest rates [63]. The e-krona pilot reflects a broader trend where CBDCs are seen as essential for ensuring continued access to risk-free central bank money and maintaining public confidence in the monetary system [63].

5.1.4 Cross-border transactions and the bandwagon effect

Despite significant improvements in domestic transfers through recent FinTech developments, there remains substantial room for improvement in cross-border fund transfers [31]. Furthermore, the more prominent cross-border transactions are in a country, the higher the need for more efficient alternative payment solutions [25]. Therefore, the adoption of CBDCs for cross-border transactions is more likely in developed countries [28]. Foreign remittances, which constitute a substantial portion of economic growth in emerging countries, are often costly and time-consuming [31]. According to a World Bank survey in mid-2021, the cost of cross-border transfers averaged 6.30 percent of the amount transferred, or 4.99 percent for digital transfers [43]. This high cost is a burden for both senders and beneficiaries [43]. Most central banks consider cross-border CBDC arrangements suitable for reducing the fees and time associated with transfers [43]. These arrangements would involve central banks and commercial banks/payment service providers from multiple countries, allowing for immediate settlement, competitive

¹A helicopter drop is an expansionary fiscal or monetary policy that is financed by an increase in an economy's money supply. It could be an increase in spending or a tax cut, but it involves printing sums of money and distributing it to the public in order to stimulate the economy [76].

exchange rates, and leveraging existing domestic payment channels [43]. Additionally, using CBDCs, which are claims on central banks, would eliminate credit risk between financial institutions involved in cross-border transactions, further reducing transaction fees [43].

The bandwagon effect also plays a significant role in the adoption of CBDCs. The bandwagon effect in this context refers to the phenomenon where the implementation of a CBDC by a major economy creates a ripple effect, prompting other countries to consider and possibly adopt their own CBDCs. For example, once a major economy like China implements its own CBDC, other countries are likely to study the phenomenon and consider implementing their own [58]. For instance, the pilot phase of e-CNY by the People's Bank of China has pressured Vietnam to develop its own CBDC infrastructure to remain competitive [58].

5.1.5 National security

Promoting national security is another motive for launching CBDCs [30]. The underlying blockchain technology can maintain a record of every transaction, which is a feature that appeals to many governments [28]. This capability has led numerous nations to consider issuing their own government-controlled digital cryptocurrencies [28]. By doing so, governments can harness the benefits of blockchain technology while also monitoring their citizens' financial transactions [28]. For instance, the Central Bank of the Bahamas described CBDCs as an effective tool to combat illicit activities such as terrorist financing and money laundering [30]. Due to the limited anonymity offered by CBDCs, it is possible to trace transactions used for illegal purposes [30]. Additionally, CBDCs equipped with smart money capabilities can deter corruption and tax evasion as well [30].

5.2 Technical design choices for CBDCs

This section examines the technical facets of CBDC implementation, including storage and management models, target audiences, distribution mechanisms, and ledger technologies. Additionally, potential offline payment solutions based on existing literature are explored. The section concludes with a discussion of real-world CBDC project examples that illustrate these various technical approaches.

5.2.1 Custodial vs Non-custodial wallets

The study found that there are two main types of digital wallets used for CBDCs. In the context of CBDC a wallet is a digital tool or application that allows users to store, manage, and transact with their digital currency. The wallet can be software-based, running on devices such as smartphones and computers, or hardware-based, utilizing

physical devices for enhanced security. Wallets in CBDC can be custodial and non-custodial. Custodial wallets are managed by a third party that holds the private keys, while non-custodial wallets allow users to hold their private keys directly [29][53].

Custodial wallets involve a third party, such as a central bank or commercial bank, managing the private keys and security aspects on behalf of the user [29][53]. This setup enhances security and reduces the risk of loss due to forgotten passwords or private keys [53].

Non-custodial wallets give users full control over their private keys and responsibility for their CBDC holdings [29][53]. This provides a cash-like feature in digital transactions but comes with higher risks, as lost keys or passwords can lead to permanent loss of funds [53].

5.2.2 Account vs Token-based CBDC

Based on the study results, it was discovered that CBDCs can either be account or token based. Account-based CBDCs involve digital currencies managed in centralized accounts with user identification, while token-based CBDCs use anonymous addresses and blockchain technology for security and peer-to-peer transactions [18][21].

Account-based CBDCs involve storing digital currencies in accounts managed by a central authority, similar to traditional bank accounts, with transactions requiring user identification [18][21]. These systems enable account recovery through identity verification if credentials are lost, offering ease of use and familiarity for users accustomed to traditional banking [21]. However, they pose privacy and cybersecurity risks due to centralized data collection and potential government surveillance [18]. Verification in account-based CBDCs involves checking the identity of account holders, which requires strong identity verification systems and internet connectivity [50]. Account-based CBDC systems are preferred by central banks for providing real-time economic monitoring and guiding monetary policy [23].

Token-based CBDCs store digital currencies in anonymous addresses, using blockchain technology and private key cryptography for security [18]. Verification relies on digital signatures, enabling secure, tamper-resistant peer-to-peer transactions without intermediaries [21]. These CBDCs ensure universal access and privacy, resembling the functionality of cash [23]. Storage can be custodial or non-custodial, with non-custodial designs providing direct control but posing risks if private keys are lost [50]. Token-based CBDCs facilitate easier cross-border transactions and offline usage but are slower and more susceptible to hacking compared to account-based systems [53]. They also present challenges in tracing money flows and enforcing anti-money laundering laws due to higher anonymity [50][53].

5.2.3 Retail vs Wholesale CBDC

The study found that CBDCs can be categorized into two types depending on their intended users: retail and wholesale. Retail CBDCs are designed for the general public, providing accessibility and financial inclusion, while wholesale CBDCs are tailored for large-value interbank transactions, enhancing settlement efficiency and security [23].

Retail CBDC is issued for the general public and can be made available through public-private partnerships with commercial banks or held directly by private individuals at the central bank. This system provides convenience, resilience, accessibility, and better tracking of payments, making CBDC widely accessible for any purpose, including peer-to-peer cross-border payments [23]. Central banks interested in addressing financial inclusion challenges are likely to consider issuing general-purpose CBDCs [50].

Wholesale CBDC is issued for large-value interbank payments, guaranteeing anonymity, restricted access to predefined economic agents, and applicability to a limited range of purposes. This design facilitates faster or immediate settlement and extended settlement hours, with broader access than central bank reserves [23]. Research and experiments on wholesale CBDCs, conducted mainly in developed economies with established interbank systems, aim to promote security and efficiency in institutional trading. These projects may also provide CBDC accounts and payment services to institutions like securities participants and non-financial companies [39]. Examples include projects like Jasper (Canada), Ubin (Singapore), and Inthanon (Thailand), which focus on improving interbank payment efficiency and securities settlement [50].

5.2.4 Direct vs Indirect vs Hybrid vs Intermediated CBDC

The research identified 4 different models for distributing and managing CBDCs. These models vary in the degree of central bank involvement and the role of intermediaries, as discussed in the rest of the section.

Direct CBDC is characterized by the central bank providing financial services directly to users and managing all transaction records. This approach transforms the traditional two-tier monetary system into a one-tier system where the central bank handles all aspects of the CBDC system, including issuance, retail payments, verification of transactions, and account maintenance [19][53]. In this model, central banks distribute CBDC themselves, necessitating an expansion of their computing and operational capacity, including Know Your Customer (KYC) processes for all accounts [22]. The direct CBDC model simplifies the infrastructure by eliminating reliance on financial intermediaries, transferring responsibilities such as customer due diligence, account management, and payment services from the private sector to the central bank [39]. While this model provides significant control and reliability, it is operationally intensive and places a substantial burden on central banks, which are typically not accustomed to managing retail user interactions at such a scale [72][44].

Indirect CBDC involves the central bank delegating the management of financial systems to intermediaries while maintaining oversight over these intermediaries. In this two-tier system, the central bank acts as a platform, issuing CBDC to authorized intermediaries who handle customer-related transactions and maintain retail accounts [19][53]. This model is less disruptive to the current financial ecosystem, as intermediaries continue to manage retail operations while the central bank focuses on wholesale accounts and broader regulatory oversight [39]. Under indirect CBDC, responsibilities such as asset issuance and network governance are shared between the public and private sectors, with intermediaries often issuing stablecoins backed by central bank reserves, known as synthetic CBDCs [22][72]. By delegating operational tasks to private partnering intermediaries, central banks can reduce their operational burden and focus on providing core CBDC infrastructure, although this approach introduces some residual default risk due to the private nature of the issuers [72][44][21]. The intermediated architecture of models like China's e-CNY demonstrates how non-central bank actors can manage customer-facing engagement, KYC-AML-CFT processes, and user services while the central bank oversees issuance and ledger validation [33].

Hybrid CBDC combines elements of both direct and indirect models, allowing central banks to collaborate with intermediaries for CBDC distribution while retaining control over core ledger functions. In this two-tiered model, central banks issue CBDC but rely on private firms for intermediary roles, such as user onboarding and retail payment management [22][72]. This approach leverages the competitive advantages and innovation potential of private actors while maintaining central bank oversight of retail records to ensure business continuity in case of intermediary failure [72]. The hybrid model, also referred to as the "Two-Tier Model," has been explored by various central banks working with the private sector, exemplified by the PBoC's Digital Currency/Electronic Payments (DC/EP) program [22][39]. Under this architecture, central banks delegate the processing of all retail transactions to intermediaries while keeping records of retail balances communicated by these intermediaries [44]. This model strikes a balance between central bank control and private sector efficiency, enhancing system resilience and potentially lowering costs in the long run [53][21]. However, setting up and operating a hybrid CBDC system may be more costly initially, requiring significant coordination and regulatory oversight [53].

Intermediated CBDC involves private actors handling the payment process, with central banks maintaining wholesale records only [72]. This model minimizes the central bank's direct involvement in retail record-keeping, relying on regulation and supervision to ensure record integrity [44]. The flexible multi-tier system allows for various roles and tiers based on specific needs, though it can be complex [21]. The e-CNY system demonstrates intermediated CBDC, with non-central-bank actors managing customer engagement and the central bank overseeing issuance and ledger validation [33]. This division of labor maintains efficiency while providing central bank oversight [33].

5.2.5 Centralized vs Decentralized vs Hybrid Ledger design

One more technical aspect the research identified is in regards to the ledger design. CBDC ledger can either be centralized (single-ledger), decentralized (distributed-ledger) or hybrid. These ledgers are discussed in the paragraphs below.

Centralized CBDC systems rely on a single central authority, like the central bank, to manage the ledger. This approach allows uniform management of the financial system but is vulnerable if the central authority is compromised [19]. These systems use permissioned blockchains and are account-based, providing direct access to the central bank but lacking anonymous exchange qualities [23]. Centralized ledgers, where a trusted administrator controls updates, are the norm in finance, exemplified by projects like the Dinero Electrónico in Ecuador [39]. Data is stored in multiple nodes but controlled centrally [50]. Central banks may also consider centralized ledgers with multiple data centers or limited offline transactions [44].

Decentralized CBDC systems use DLT, where transaction records are shared and synchronized across multiple entities, providing transparency and reducing attack risks [19]. Decentralized CBDCs could be based on permissionless blockchains, achieving full decentralization and offering cash-like features [23]. DLT-based CBDCs are adopted by central banks in countries like Brazil, Cambodia, and China [39]. These systems enhance accessibility, resilience, and transparency but pose operational and security risks [39]. In distributed ledgers, multiple nodes store data simultaneously, requiring consensus, which offers security but reduces transaction speed compared to centralized systems [50].

Hybrid CBDC systems blend centralized and decentralized elements, providing central bank accounts for intermediaries while allowing other participants to access CBDC tokens [23]. These systems balance centralized control and decentralized resilience, using authorized verifiers for validation in DLT-based setups [39]. Central banks might adopt a centralized ledger with decentralized features, like caps on offline transactions or DLT for wholesale payments [44]. Hybrid CBDCs aim to combine the benefits of both models, ensuring security, efficiency, and resilience [50].

5.2.6 Offline payments

The review also identified offline payment capability as a hot topic in the CBDC area. This is because offline payments are crucial in areas with limited internet connectivity, offering convenience, accessibility, and promoting financial inclusion by enabling transactions in remote locations and during internet outages [45]. Chaum and Brands noted the cost efficiency and speed of offline payments, along with reduced database size for bank transactions [19]. Eslami and Talebi proposed an untraceable offline e-cash system using the ElGamal signature scheme to ensure user privacy and prevent double spending by revealing the identity of offenders. However, Wang et al. identified vulnerabilities in this system, such as susceptibility to man-in-the-middle attacks [19]. To address the

increased risk of malicious actions in offline payments, Camenisch et al. proposed using a trustee to oversee transactions and prevent double spending while ensuring anonymity and security [19].

Building on these concepts, Visa’s offline payment system (OPS) protocol, based on Christodorescu et al.’s research, enables secure point-to-point payments using trusted execution environments (TEEs) on personal devices, thus allowing transactions even without internet connectivity [19][63]. This system prevents double spending through digital signatures and cryptographic protocols, creating a resilient payment ecosystem [63]. Moreover, CBDCs can be designed for offline transactions via SMS or completely offline access, as demonstrated by Nigeria’s eNaira and Ghana’s E-Cedi, which support consecutive offline payments, enhancing their utility in regions with limited connectivity [62]. Similarly, Russia’s digital ruble supports offline payments by allowing transfers between offline-capable devices without an internet connection, ensuring financial inclusion and security even in remote areas [71].

In terms of system operation, fully offline systems require preparation and are transitive, allowing funds received offline to be re-spent without online synchronization. In contrast, intermittently offline systems enable transactions during temporary internet outages but are non-transitive, meaning funds received offline cannot be re-spent until reconnected to the internet [45]. Integrating these offline capabilities in CBDC design ensures real-time, secure transactions without continuous digital connectivity, thereby enhancing the overall resilience and inclusivity of digital currencies [63].

5.2.7 CBDC projects from the real world

The study analyzes several pilot projects and real-world implementations of CBDC to comprehensively assess progress in the field. Projects were evaluated across jurisdictions, diverse goals, and countries with varying economic levels. While numerous CBDC projects were initially considered, four were ultimately selected based on their unique goals and the availability of high-quality, comprehensive data: Project Jasper (Bank of Canada), Project Blockbuster (Deutsche Bundesbank), Project SALT (Central Bank of Brazil), and Project Inthanon-LionRock (Bank of Thailand and Hong Kong Monetary Authority). Given their distinct objectives and independent nature, these projects are discussed in alphabetical order.

Project Blockbuster In March 2016, the Deutsche Börse Group and Deutsche Bundesbank launched Project Blockbuster to explore blockchain technology for improving back-office services in Germany’s securities settlement Financial Market Infrastructure (FMI). The primary objective was to develop a DLT-based Securities Settlement System (SSS) prototype for settling securities for cash. This project developed prototypes on both Hyperledger Fabric and Digital Assets platforms, involving key entities such as the Coin Providing Authority (CPA), Coin Distributor (CD), Bond Providing Authority (BPA),

Bond Distributor (BD), and Corporate Action Executor (CAE), supporting various types of settlements [17].

The Hyperledger Fabric-based prototype initially used Fabric v0.6 and later transitioned to Fabric v1.0, shifting from PBFT to PoA to enhance scalability. Validator nodes (CPA and BPA) were responsible for validating transactions, while non-validator nodes (CD and BD) published transactions. Performance evaluations revealed high throughput but noted transaction conflicts due to architectural differences, which were addressed in subsequent updates. Despite variations in throughput and latency based on chaincode complexity, the prototype demonstrated the feasibility of using Fabric for securities settlement [17].

Meanwhile, the Digital Assets (DA)-based prototype evaluated the SSS performance on a different DLT platform, consisting of application, business logic, and distributed ledger layers. This implementation introduced roles for operators and participants, with nodes deployed in an AWS-hosted environment. Functional assessments using various test scenarios indicated that increased transaction volumes led to higher throughput with minimal increases in latency and memory usage. The DA prototype met stress testing and scalability benchmarks, demonstrating its capability to handle large transaction volumes effectively [17].

Project Inthanon-LionRock Initiated in May 2019, Project Inthanon-LionRock is a collaboration between the Bank of Thailand (BOT) and the Hong Kong Monetary Authority (HKMA) to explore CBDC for cross-border payments. The project developed a Thai Baht (THB)–Hong Kong Dollar (HKD) corridor network, allowing banks in both countries to conduct peer-to-peer funds transfers and foreign exchange (FX) transactions, enhancing real-time and atomic PvP settlements. Completed in December 2019, the DLT-based PoC included ten participating banks [60].

The THB-HKD corridor network connects the domestic W-CBDC payment networks of Thailand and Hong Kong. Each participating bank has nodes on both the local and corridor networks, while the central banks share control of the "operator node" in the corridor network. Each central bank issues its own W-CBDC, with domestic networks handling local settlements and the corridor network facilitating cross-border transactions using Depository Receipts (DRs) denominated in domestic currency. The corridor network supports liquidity management, gridlock resolution, and FX transactions, with finality ensured by smart contracts [60].

Cross-border fund transfers involve sending instructions from one bank to another, either within the same country or internationally. Transactions settle instantly if funds are available or queue until sufficient liquidity is available. FX transactions can be conducted via Board Rate, Request for Quote, or Off-corridor Arrangement, all settling in an atomic PvP manner with smart contracts tracking the process. The PoC demonstrated significant benefits such as reduced settlement time, enhanced liquidity efficiency, better regulatory

compliance, and improved reporting capabilities [60].

Project Jasper Project Jasper was a collaboration between Payments Canada, the Bank of Canada, Canadian commercial banks (CMBs), and R3. The first phase developed a PoC prototype using Ethereum DLT for the wholesale interbank payment system, utilizing Digital Depository Receipts (DDRs) backed by cash from CMBs. The Bank of Canada issued DDRs and managed wallets, while CMBs could create accounts and execute transactions. Despite enabling pledging, generating, exchanging, and redeeming DDRs, the system faced challenges with throughput, data privacy, and settlement finality due to Ethereum's limitations and the PoW consensus mechanism [17]. In Phase II, the project expanded participation and introduced a Corda-based atomic settlement and liquidity-savings mechanism (LSM) settlement option. The Bank of Canada, acting as the notary and supervisory node, ensured settlement finality but introduced a single point of failure risk. The system improved scalability and data privacy compared to Phase I, but reliance on a single node for transaction processing reduced overall resiliency [17]. Phase III focused on integrated securities settlement using DLT, facilitating the exchange of multiple asset types on a shared ledger. Implemented on Corda v2.0 and hosted on Microsoft Azure, this phase involved participants like Payments Canada, the Bank of Canada, TMX Group, Accenture, and R3. The project developed tokenized cash and equity assets for delivery-versus-payment (DvP) settlements, enhancing cash-equity interactions and immediate settlement finality. Observations highlighted technical and cash efficiency, with atomic settlement functionality allowing for the immediate reuse of assets post-transaction [17].

Project SALT The Central Bank of Brazil launched Project SALT to develop a backup real-time gross settlement (RTGS) system for inter-bank payment settlements among wholesale institutions. Using the BlockApps platform, Phase I implemented a simplified version of SALT with both central and commercial bank nodes acting as validators, employing a PoW consensus mechanism. Smart contracts facilitated the decentralized exchange of Brazilian Digital Currency – Real (BRL-DDR) and prevented double-spending. However, the prototype faced data privacy challenges, as the central bank's solution introduced inefficiencies and bottlenecks, and the transaction key protocol lacked strong forward secrecy unless key pairs were regularly changed [17].

In Phase II, the project aimed to explore alternative DLT platforms to address the data privacy issues from Phase I. Initially, the project utilized the Fabric v0.6 platform, employing the PBFT consensus mechanism. This version distinguished between validating and non-validating nodes, with only the former achieving transaction consensus. Despite these changes, the Fabric prototype encountered similar data privacy challenges as the BlockApps implementation in Phase I [17].

The second iteration of Phase II was implemented on Quorum, an Ethereum fork,

allowing code reuse from the Phase I BlockApps prototype. QuorumChain was used as the consensus mechanism, providing enhanced data privacy guarantees compared to previous iterations. However, this improvement in data privacy came at the cost of weaker assurances against double-spending [17].

5.3 Challenges associated with CBDCs

The study reveals several challenges associated with CBDCs from various perspectives. The research identified a number of factors including technological, societal, financial, and legal. While several political challenges are identified as well, they are not discussed in the paper due to the lack of in-depth data in regards to political challenges. The challenges are organized with the most frequently cited issues appearing first, followed by those with less supporting data.

5.3.1 Technological challenges

CBDCs face significant technological challenges that must be addressed to ensure their successful implementation and adoption. These challenges encompass cybersecurity threats, double spending, repudiation, privacy concerns, and interoperability issues.

As an entirely digital form of money, CBDCs are inherently vulnerable to cybersecurity threats, including hacking and user data breaches, which could lead to substantial financial losses and undermine public trust [18][21][32]. The widespread use of digital services makes financial market infrastructures more vulnerable to cyberattacks, especially in developed economies where the financial sector is highly digitized and frequently targeted by criminals [43]. Another critical challenge is repudiation, where the entity receiving the digital currency might maliciously insist they did not receive it or that the currency is fake. To prevent such cases, non-repudiation requires the system to record all transaction details unalterably, providing proof of integrity and origin that can be verified by third parties [19]. However, permissioned CBDCs, which rely on approved authorities to verify transactions, are vulnerable to blockchain manipulation and thus require additional security safeguards [19]. In addition to cybersecurity and repudiation, a major issue in digital currencies is double spending, defined as the potential flaw where the same digital token can be spent more than once [19]. To detect and penalize malicious acts that evade security protocols, the electronic financial system should be verifiable, ensuring that transactions are recorded and cannot be falsified [19].

Privacy concerns are paramount, as CBDCs can compromise the anonymity traditionally associated with cash. Providing complete anonymity in CBDCs can cause the same money-laundering problems that occur in conventional financial systems [19]. Therefore, balancing privacy with regulatory requirements like KYC (Know Your Customer) and AML (Anti-Money Laundering) is a complex task [29][32]. Central banks often struggle with creating CBDCs that balance anonymity and user registration [65]. Pure anonymity

could pose risks regarding cyber hackers, money laundering, and other illicit acts [65]. Consequently, CBDCs must also address verifiability issues to ensure transactions are recorded accurately and are tamper-proof [19].

Finally, currently, there is a risk that the global CBDC ecosystem becomes fragmented, as many central banks develop their own digital currencies based on different technologies, standards, and protocols [43]. Creating interoperability and interconnectivity between different CBDCs is crucial to exploit their potential while preserving strategic autonomy [65]. If each CBDC project is built on its own system, it may mean that those systems are unable to communicate with one another, potentially delaying and deterring collaborative projects such as cross-border remittances [65]. Lastly, developing a CBDC would require significant investment in technology and systems to support a new CBDC payments infrastructure [59].

5.3.2 Societal challenges

Societal challenges for CBDCs are unique issues that vary across different countries and regions, impacting the successful implementation and adoption of these digital currencies. These challenges include technological infrastructure, accessibility, competition with existing digital payment systems, technological literacy, public trust in central banks, and cash reliance. It should be noted that the technological infrastructure challenges here do not pertain to the CBDC technology itself but rather to the groundwork that central banks must establish for nationwide CBDC implementation.

CBDCs face societal challenges that must be addressed to ensure their successful implementation and adoption. In countries like the Philippines, the high dependence on cash and insufficient technology spread make the launch of CBDCs implausible [16]. Similarly, the lack of necessary infrastructure, such as internet access and smartphones, in countries like Ukraine and India poses a major obstacle to the adoption of CBDCs [16][18]. Moreover, the requirement for 24-hour internet access could lead to system blackouts during internet shutdowns, eroding public trust in CBDCs [18]. Additionally, the presence of well-established digital payment systems, such as Alipay and WeChat Pay in China, and Google Pay, PayTM, and PhonePe in India, can hinder the acceptance of CBDCs, as these platforms already meet the needs of the populace [38]. Consequently, this competition between CBDCs and existing digital payment platforms may lead to users seeing no advantage in using CBDCs over other digital payment solutions [38]. Central banks must navigate the balance between providing a secure, reliable CBDC and avoiding the crowding out of private payment solutions [43]. The success of CBDCs hinges on their ability to meet unmet user needs, leverage existing technology, and address cultural and demographic factors [49]. For instance, in Uruguay's e-Peso pilot, it was found that addressing financial inclusion and cultural aspects is crucial for CBDC adoption [49]. Therefore, effective CBDC implementation involves crafting adaptation strategies that tackle consumer apprehensions and ensuring high-level security, reliability,

and ease of use [49].

Furthermore, the technological literacy of the population is another significant barrier. Many people lack the digital skills necessary to use CBDCs, which could lead to private key losses and digital currency fraud [21][38]. This gap is particularly pronounced in rural areas and among older populations, as evidenced by low adoption rates of digital currencies like the e-Peso in Uruguay and the Sand Dollar in the Bahamas [38]. Therefore, addressing these challenges requires investments in infrastructure, digital literacy programs, intuitive user interfaces, and robust security standards [21]. Public trust in central banks and their digital currencies also varies significantly between countries. In nations with stable fiat currencies and strong trust in institutions, CBDCs are more likely to be accepted [38]. Conversely, in countries with less stable currencies and lower trust in institutions, the adoption of cryptocurrencies is higher, posing a challenge for CBDC acceptance [38].

The reliance on the traditional cash economy among the unbanked or underserved populations in emerging markets limits the effectiveness of CBDCs in enhancing financial inclusion [53]. Even with access to digital financial services, adequate opportunities to spend digital currency or cash out with ease remain critical necessities [53]. Consequently, for CBDCs to realize their potential, governments and internet service providers need to collaborate to build affordable internet infrastructure, and mobile wallets must function in low-bandwidth areas [65]. Additionally, increasing financial literacy is essential to protect consumers and facilitate the transition to digital currencies [65].

5.3.3 Financial challenges

Financial challenges associated with CBDCs encompass a range of issues that could destabilize financial systems. These challenges include the risk of financial instability due to bank disintermediation, substantial infrastructure and technology investment requirements, and competitive pressures that could disrupt conventional financial institutions and create international financial spillovers.

CBDCs pose numerous financial challenges, particularly concerning the potential for financial instability. One primary concern is the risk of financial instability through the disintermediation of banks. Researchers fear a large-scale flight of capital from bank deposits to CBDCs, shrinking commercial banks' balance sheets and decreasing the credit multiplier mechanism, which could lead to a 'credit crunch' and ultimately an economic recession [18]. Individuals might shift to CBDCs for transactions due to lower costs and faster services, potentially causing a 'crisis of confidence' in the banking system and triggering bank runs, resulting in bank failures and higher capital costs for borrowers [18][21][53]. Consequently, issuing a CBDC, central banks may engage in competition with commercial banks, central counterparties, other payment system operators, and even other central banks. This competition could crowd out conventional financial institutions and distort the financial system, reducing overall stability [50][53].

Moreover, real-time retail payment systems, including CBDCs, involve substantial costs [21]. The untested nature of CBDCs could lead to monetary policy mistakes, threatening systemic stability. For example, if sovereign retail CBDCs yielded a rate of return similar to deposit accounts, there would be a logical preference to hold CBDCs in digital wallets rather than banks [20][21]. Furthermore, the introduction of CBDCs could result in international financial spillovers, increasing exchange-rate volatility and affecting capital flow dynamics. This is particularly concerning for emerging markets and developing economies, which may face challenges with currency substitution due to the availability of CBDCs from larger economies [53][65][68][69].

5.3.4 Legal challenges

CBDC issuance presents significant legal challenges that require comprehensive revisions to existing laws and regulations. These challenges encompass ensuring compliance with AML and CFT requirements, addressing the legal status of CBDCs as legal tender, and establishing robust legal frameworks to protect personal data while allowing the tracing of illicit payments. Consequently, robust legal underpinnings are essential for the credibility and acceptance of CBDCs, requiring frameworks to address central bank authority, legal tender status, and the balance between combating illicit activities and protecting privacy [70].

Central banks introducing CBDCs must ensure compliance with AML and CFT requirements and satisfy the public policy requirements of supervisory and tax regimes [23]. The relationship between AML and CBDC implementation is complex; while CBDCs could potentially facilitate money laundering due to their anonymity and accessibility, authorities must carefully consider the potential impacts as they develop and implement CBDCs [32]. Legal frameworks must address the confidentiality of personal data while allowing the tracing of illicit payments to identify criminals, a dual requirement that can generally only be met with appropriate legal guarantees [43].

In many countries, fundamental laws define the national currency as legal tender. Given that these legal definitions were established when digital money was not conceivable, it is crucial to determine whether CBDC issuance can be legally equated with banknote issuance and whether it can be deemed legal tender under existing legislation [43]. Central bank laws typically do not allow direct central bank accounts for individuals or businesses. Therefore, intermediaries such as commercial banks and regulated non-bank financial service providers may be necessary to manage CBDC holdings and payments. A recent IMF paper found that only 40 out of 174 central banks surveyed were legally permitted to issue digital currencies. Furthermore, legal implications depend on the design of CBDCs; for example, token-based CBDCs may require more fundamental legal changes than account-based CBDCs, which are already used at the wholesale level [70]. For instance, the issuance of a Vietnamese CBDC as a new type of Vietnamese Dong currency would require amendments to the Law on the State Bank of Vietnam

to prevent inconsistencies between physical and digital money [58]. Additionally, in Denmark, Danmarks Nationalbank would involve the political system to obtain a parliamentary decision if a retail CBDC is to have legal tender status [52]. Similarly, the introduction of a digital euro would raise several legal issues related to Central Bank Law, Monetary Law, and the EU legislative framework on payments [67]. Therefore, the ECB would require changes to its current mandate to introduce a retail digital Euro, highlighting the need for amendments to central bank mandates to support CBDC issuance [43].

Besides central bank and monetary policy laws, CBDCs could raise legal issues in tax, property, contracts, insolvency, and payments-related laws. Policymakers and regulators must establish an appropriate regulatory environment, including common standards for private sector development of robust CBDC-based applications [70].

5.4 Potential impacts of CBDCs

Finally, as a part of the last research question, the potential impacts of CBDCs are assessed. These impacts are categorized into three areas: financial, technological, and financial inclusion. The financial impact of CBDCs pertains to their influence on monetary policy, banking sector dynamics, and overall financial stability. In contrast, the financial inclusion impact focuses on the ability of CBDCs to provide access to financial services for underserved or excluded populations. The subsections are ordered based on the amount of data found for each category, from most to least.

5.4.1 Impact from financial perspective

The introduction of CBDCs has far-reaching implications for the financial system, impacting various aspects such as monetary policy, banking sector dynamics, liquidity and lending practices, market stability, regulatory oversight, and competitive positioning. These impacts stem from the fundamental changes that CBDCs introduce to the mechanisms of currency issuance, distribution, and utilization within the economy.

One significant area of impact is monetary policy, where CBDCs can enhance the interest rate channel of the monetary transmission mechanism. The presence of a national retail CBDC, such as the e-hryvnia, can increase the elasticity of market interest rates on deposits and loans by linking the return on CBDC holdings directly to the key policy rate [16][18]. This connection is expected to accelerate banks' response to changes in the central bank's rates, thereby improving the overall effectiveness of monetary policy [23][42].

The banking sector is significantly impacted by the introduction of CBDCs. A CBDC can create direct competition with commercial banks by offering an alternative means for individuals to store and transact money, potentially leading to increased deposit rates as banks strive to retain their customer base, thereby increasing the cost of raising funds for

commercial banks [16][17][23][34]. Furthermore, the issuance of CBDCs could disrupt the traditional banking model by disintermediating banks², which might destabilize financial institutions and the broader financial system [34][73]. Interest-bearing CBDCs, in particular, can compete directly with commercial bank deposits, affecting the size and cost of the deposit base, which is a primary source of funding for banks [66]. This competition might lead banks to raise deposit rates or seek alternative funding sources, impacting lending rates and overall banking profitability [16][17][23][34][66][73]. The model and characteristics of CBDCs will play a crucial role in determining their competitive position relative to bank deposits and cash [16][17][23][34][66][73].

Additionally, CBDCs influence liquidity and lending practices within the banking sector. By providing a more straightforward method for central banks to offer short-term liquidity to commercial banks, CBDCs can mitigate the risk of bank failures during financial distress [18]. However, the potential for increased liquidity risk arises if customers predominantly deposit with central banks rather than commercial banks, exacerbating the possibility of bank runs³ [23][27][34][66].

The broader financial system and market stability are likely to be affected by CBDCs through improvements in efficiency and operational practices. CBDCs can enhance the safety and efficiency of payment systems and reduce cash management costs [23][33][34][40][50]. Stability and risk management within the financial sector can be bolstered by CBDCs, which help mitigate leverage and asset risks, contributing to overall financial stability [23][34][73].

Regulatory and supervisory impacts of CBDCs are also significant. CBDCs provide central banks and regulators with enhanced tools for monitoring and supervision [33]. The ability to closely track currency use and implement precise monetary policy adjustments can improve the responsiveness of monetary policy to complex macroeconomic situations [50][59].

5.4.2 Impact from technological perspective

The impact of CBDCs from a technological perspective encompasses the ways in which these digital currencies can transform and enhance the existing financial infrastructure. This includes improvements in payment system resilience, efficiency, and interoperability, as well as fostering innovation through the integration of advanced technologies such as DLT. Additionally, technological impacts involve the potential for new business models and enhanced capabilities within the financial ecosystem.

The introduction of CBDCs presents significant technological impacts, particularly in

²Banking disintermediation refers to the process where borrowers and savers bypass traditional banks to engage in direct financial transactions, often through alternative financial markets or instruments. This reduces the role of banks as intermediaries in the financial system.

³A bank run is a situation where a large number of customers simultaneously withdraw their deposits from a bank or financial institution due to fears about its solvency.

enhancing payment systems and fostering innovation. One key benefit is the potential for collaboration between payment technology companies and central banks. This alliance combines the trust and security of central banks with the dynamism and innovation of e-payment companies, as demonstrated by the implementation of CBDC in the Bahamas, where several e-payment companies are involved in its implementation and operation [31].

CBDCs can enhance the resilience of payment systems by promoting interoperability between different electronic payment platforms, reducing barriers, and stabilizing digital private payment networks, including stablecoins. For example, linking different payment systems through application programming interfaces (APIs), similar to open banking frameworks, can streamline interactions between disparate payment networks, increasing network externalities and overall system stability [50][53]. Leveraging DLT has enabled the issuance of CBDCs and improved central banks' operational efficiency domestically and across borders. Projects like Blockbuster in Germany and Jasper-Ubin in Canada and Singapore have demonstrated how blockchain can support more resilient Financial Market Infrastructures (FMIs), enhance public trust, and meet requirements for data privacy (e.g., Inthanon I), transaction scalability (e.g., Khokha), settlement finality (e.g., Ubin Phase II), and operational risk management (e.g., Jasper Phase II) [17]. Furthermore, this interoperability facilitates cross-border payments, significantly reduces cross-currency exchange rate risk, and lowers transaction costs, benefiting lower socioeconomic groups [50][53]. Additionally, CBDCs can promote the digitization of value chains in various sectors, such as agriculture, by facilitating person-to-business and business-to-business payments [50].

Improving the technological form of central bank money through CBDCs can ensure continued relevance and usefulness. For instance, a CBDC could provide instant electronic peer-to-peer settlement, enhancing convenience and safety for in-person transactions like those at farmers' markets. Additionally, a token-based CBDC could incorporate advanced technological benefits, such as programmable money for executing contracts or specific actions, reducing the need for manual or third-party processing and generating efficiencies [59].

5.4.3 Impact from financial inclusion perspective

The impact of CBDCs on financial inclusion refers to the potential of CBDCs to provide access to financial services for individuals and groups who are currently underserved or excluded from the traditional banking system. By leveraging digital technologies, CBDCs can overcome barriers to financial access, ensuring that a broader segment of the population can participate in the financial system.

The introduction of CBDCs holds significant potential for enhancing financial inclusion. CBDCs can facilitate financial and digital inclusion for individuals and groups currently outside the banking system or wary of using existing digital payment systems

that are not backed by the central bank [18]. With adequate online and offline capabilities, CBDCs can ensure universal access to financial services, thereby enhancing overall money circulation and accessibility to financial resources for those excluded from traditional banking services [30][49].

In developing and poor countries, many informal workers, such as local waste pickers, are often paid in cash due to the lack of formal bank accounts. A CBDC can change this by allowing employers to pay wages into account-based CBDC wallets, even if workers do not have formal bank accounts, thus integrating informal workers into the formal financial system [40]. This can contribute to economic growth and stability as it brings more people into the financial fold [49].

CBDCs can address the insufficient reach of existing payment systems by implementing digital distribution channels and ICT infrastructure, providing access to central bank money to most of the population. They offer a government-authorized solution for storing value and making payments and can be a useful channel for economic stimulus payments to individuals and businesses, especially in times of crisis [50].

By providing basic saving and payment services at low or subsidized prices, CBDCs can benefit unbanked or underserved populations. Acting as a public good, CBDCs can serve as a gateway to formal financial inclusion for those reliant on cash or facing barriers to the banking sector. For example, the Bahamas issued a CBDC to encourage cash-reliant communities to switch to digital saving and paying, potentially leading households to access other financial services like small-business loans and investments. India's Unified Payments Interface similarly increased financial inclusion significantly by coupling national digital identity with open-data frameworks [59].

6 Discussion

This thesis section discusses the results and presents a table which shows the current state of CBDC.

The first research question is “What are the driving forces motivating central banks and governments explore CBDC?” The results show that the motivations can be grouped under 5 categories: financial inclusion, money digitalization, monetary sovereignty and financial stability, cross-border transactions and bandwagon effect, national security.

Financial inclusion remains a critical issue in emerging markets due to barriers like formal identification requirements, minimum deposit mandates, and lack of local bank branches. CBDCs offer a potential solution by enabling digital financial inclusion, as demonstrated by Uruguay's e-peso and the Bahamas' Sand Dollar, which have integrated the informal economy, reduced costs, and improved payment services [30][39]. These initiatives show that CBDCs can facilitate access to financial products for small businesses and individuals in remote areas by leveraging high mobile phone ownership [30]. In developed nations, the shift towards digital financial markets and cashless transactions,

along with the rise of stablecoins from Big Tech, is driving central banks to adopt retail CBDCs to maintain financial stability and counter systemic risks [43]. For instance, the Libra/Diem project by Facebook highlighted significant market interest in digital currencies, prompting central banks to act proactively [43]. Projects like China's e-CNY and India's Digital Rupee aim to mitigate threats from private cryptocurrencies and enhance payment systems [33][18][43]. CBDCs also offer central banks enhanced tools for monetary policy, crucial for managing money supply and interest rates, particularly in scenarios involving zero or negative interest rates, as seen with Sweden's e-krona [63]. Additionally, CBDCs can address inefficiencies and high costs in cross-border transactions, providing lower fees, faster settlements, and reduced counterparty risk [31][43]. This is especially beneficial for emerging economies that rely on remittances for economic growth. The global adoption of CBDCs is further influenced by the bandwagon effect, where major economies like China prompt others to follow suit [58]. Lastly, national security concerns such as combating money laundering and terrorist financing motivate CBDC development due to the transparency and traceability of blockchain technology, although balancing privacy and security remains crucial [28][30]. For example, the Central Bank of the Bahamas has emphasized the potential of CBDCs in deterring corruption and tax evasion through limited anonymity and programmable features [30].

Based on the data, it appears that the launch of retail CBDCs in developed countries primarily aims to improve the efficiency of domestic payments, enhance payment security, and ensure financial stability [16]. In these advanced economies, the development of financial markets and the shift towards cashless transactions are key factors driving the adoption of retail CBDCs [25]. Consequently, the adoption of wholesale CBDCs for cross-border transactions is more likely in developed countries, where the main concerns are payment safety and improving the efficiency of international payments [28]. Traditional bank-provided cross-border money transfer solutions are often inefficient and expensive, leading to the rise of digital payment solutions from private technology platforms such as Revolut and Wise. Additionally, the popularity of cryptocurrencies, including stablecoins, has soared in the past decade. Their increased accessibility has made them a low-cost and fast way of transferring money globally. These observations collectively indicate that there are now numerous cross-border payment methods provided by FinTech companies and cryptocurrencies, effectively bypassing traditional banking systems, which can pose a threat to the authority and policies of central banks.

The data allows to make an observation in terms of comparing CBDC pursuit in emerging and advanced economies as well. In general, advanced economies have weaker motivations to launch CBDCs, often viewing them as solutions searching for problems to resolve [30]. Emerging market economies, on the other hand, demonstrate a much higher overall interest in CBDC projects, driven by varied motivations ranging from improving domestic payments efficiency to financial inclusion. This greater level of

interest is more likely to lead to actual CBDC implementation, as evidenced by the digital Bahamian dollar (Sand Dollar). This is because, emerging market economies emphasize the practical implementation of CBDCs to address a broader variety of challenges, making them more likely to pursue these projects compared to developed economies [50].

The second research question, “What possible technical ways of implementing a CBDC exist?”, explored the technical design choices for a CBDC and presented some pilot projects from the real world.

The study explored various technical approaches for implementing CBDCs, highlighting key dimensions such as wallet types, CBDC models, ledger designs, and their applications in pilot projects. Custodial wallets, managed by banks, offer enhanced security, while non-custodial wallets give users control over their keys but pose higher risks [29][53]. CBDCs can be account-based, providing easier recovery of credentials but with privacy risks, or token-based, offering anonymity but susceptible to hacking [18][21][50][53]. Retail CBDCs promote financial inclusion, supporting peer-to-peer and cross-border transactions, whereas wholesale CBDCs enhance interbank settlements [23][39][50]. Four models for CBDC distribution—direct, indirect, hybrid, and intermediated—vary in central bank involvement and operational responsibilities [19][22][33][39][44][53][72]. Direct models simplify infrastructure but increase operational burden, while indirect and hybrid models balance oversight with reduced direct responsibilities [22][39][53][72]. Intermediated CBDC involves private actors managing the payment process, with central banks maintaining wholesale records only, ensuring efficiency and oversight [33][44][72]. Ledger designs can be centralized, decentralized, or hybrid, each with trade-offs in management and resilience [19][23][39][44][50]. Centralized ledgers offer uniform management but are more vulnerable to single points of failure, while decentralized ledgers enhance security through distributed networks but may suffer from lower transaction speeds. Hybrid ledgers attempt to balance these trade-offs by combining elements of both centralized and decentralized systems. Offline payment capability, crucial for areas with limited internet, is exemplified by systems like Visa’s OPS [19][45][62][63]. This capability is vital for maintaining financial services during internet outages or in remote regions, ensuring broader financial inclusion. Pilot projects such as Project Jasper and Project Inthanon-LionRock demonstrate blockchain’s scalability and efficiency in interbank and cross-border payments, though challenges in throughput and privacy remain [17][60]. These projects underscore the importance of scalable, private, and interoperable technological frameworks for effective CBDC deployment across diverse economic environments, emphasizing the need for adaptable solutions to address various operational challenges. Moreover, these pilot initiatives highlight the potential of CBDCs to revolutionize traditional banking systems by introducing more efficient, secure, and inclusive financial infrastructures.

The findings seem to indicate that there is no single correct approach to building

a CBDC. There is ample room for flexibility in the design of CBDCs to meet diverse economic and social needs, balancing security, autonomy, privacy, and ease of use, while addressing both public and institutional requirements and ensuring effectiveness in areas with limited connectivity. The different design choices allow central banks to create CBDCs for different use cases. For example, in use cases where privacy is vital, it is unlikely for a bank to choose Ethereum as the underlying technology as Ethereum is a permissionless DLT platform, meaning all transaction data could be accessible to all participants in the system [17].

Additionally, the underlying objectives of a CBDC influence the priorities of the issuing central bank. For instance, if the CBDC is designed for cross-border transactions, ensuring compatibility with other CBDCs becomes paramount. This necessitates adopting standardized protocols and messaging systems. For example, one way to achieve this in Europe would be to integrate the digital euro into the Single Euro Payments Area (SEPA) framework among its members. Such interoperability would streamline the distribution and acceptance of the digital currency [82]. Conversely, if the goal is to enhance financial inclusion, the CBDC should be universally accessible, transactable at minimal or no cost, and closely linked to bank accounts or cash equivalents [82].

Research question "What challenges are associated with CBDC?" explored challenges of different natures associated with CBDCs. The study identified and categorized challenges under four main categories. These categories are technological, societal, financial, and legal.

The development and implementation of CBDCs face numerous technological, societal, financial, and legal challenges. Technologically, issues such as cybersecurity threats, double spending, repudiation, privacy concerns, and interoperability need robust solutions to ensure secure and reliable CBDC systems [18][21][32]. The risk of hacking and data breaches could undermine public trust and lead to significant financial losses. Furthermore, implementing robust verification mechanisms is crucial to prevent double spending, and ensuring systems that unalterably record transaction details can address repudiation issues [19]. Societal challenges vary by region and include technological infrastructure, accessibility, competition with existing digital payment systems, technological literacy, and public trust in central banks. Overcoming these barriers requires strategic investments in infrastructure, digital literacy programs, intuitive user interfaces, and security standards [16][18][21]. Financially, the risk of bank disintermediation, potential for bank runs, and the significant costs associated with CBDC implementation pose threats to financial stability [18][21][53]. A substantial shift of capital from bank deposits to CBDCs could shrink commercial banks' balance sheets, decrease the credit multiplier, and lead to economic instability [18]. The untested nature of CBDCs also brings the risk of monetary policy mistakes and potential international financial spillovers [53][65][68][69]. Legally, comprehensive revisions to existing laws are necessary to ensure AML/CFT compliance, data protection, and the legal authority for central

banks to issue digital currencies [32][43][70]. For instance, countries like Vietnam and Denmark need legal amendments to accommodate CBDCs [52][58]. Addressing these challenges involves collaboration between governments, financial institutions, and technology providers to create a secure, accessible, and legally sound CBDC infrastructure that balances privacy with regulatory requirements. Policymakers must also consider the implications of CBDCs on tax, property, contracts, insolvency, and payment-related laws to establish a robust regulatory environment.

Based on findings, several observations can be made. Firstly, CBDCs are seen as an attractive asset in the eyes of hackers given its financial nature as well as the abundance of user data associated with CBDCs. Therefore, it is vital for Central Banks to guard these data safely against data breaches, blockchain manipulations, or any other hacking events such as double spending or repudiation which could lead to a loss of public trust [18][19][21][22]. Furthermore, to avoid CBDC ecosystem fragmentation, central banks should collaborate among themselves and agree upon standards, technologies, and regulations [66]. When it comes to societal challenges, there is no common pattern as they tend to differ across countries. However, if a CBDC that meets user demands is launched, it has a chance to benefit consumers due to increased competition [49]. Consequently, this could lead to a situation where the central bank is engaged in a competition with commercial banks [50]. For example, an interest-bearing CBDC could lead to consumers withdrawing their money from commercial banks and instead storing it as CBDC. This shift could not only result in a bank run but also deposit outflows, increased funding costs for banks, reduced bank revenues, higher liquidity requirements, and a tendency for banks to engage in riskier activities to achieve higher returns [74].

Another challenge central banks need to address is the infiltration of foreign CBDCs into their own countries, particularly during times of crisis. This issue is especially pertinent for emerging markets and developing economies. A shift towards foreign CBDCs could destabilize domestic monetary policy and the banking system. In such scenarios, jurisdictions might consider implementing capital flow management measures in the design of their CBDCs [62].

Finally, it can be observed that there are two main legal challenges: existing legal permits and AML/CFT compliance. Legal frameworks need to ensure the confidentiality of personal data while also enabling the tracing of illicit payments to identify criminals. This dual requirement typically necessitates appropriate legal guarantees [29][32][43][65].

The final research question is "What is the expected impact of CBDCs?" This results to research question revealed three primary impact areas of CBDCs that are financial, technological, and financial inclusion.

Financially, CBDCs have significant implications for monetary policy, banking dynamics, liquidity, and market stability. By linking CBDC returns to the key policy rate, they can enhance monetary policy effectiveness, as seen in projects like the e-hryvnia

[16][18][23][42]. However, their introduction may disrupt traditional banking by creating direct competition with commercial banks, leading to increased deposit rates and higher funding costs as banks strive to retain customers [16][17][23][34]. Additionally, the risk of disintermediation, where customers favor CBDCs over bank deposits, could destabilize financial institutions and impact lending practices [34][66][73]. While CBDCs enhance regulatory oversight, they also require substantial infrastructure investments [33][50][59]. Technologically, CBDCs promise to enhance payment system resilience, efficiency, and interoperability through advanced technologies like DLT [17][31][50][53]. For instance, projects such as Blockbuster and Jasper-Ubin demonstrate how blockchain can improve financial market infrastructure and operational efficiency [17]. Moreover, CBDCs can streamline cross-border payments, reduce transaction costs, and leverage APIs for better interoperability, benefiting lower socioeconomic groups [50][53]. They also offer programmable features for automated contract execution, reducing the need for manual processing [59]. From a financial inclusion perspective, CBDCs hold significant potential to provide access to financial services for underserved populations, overcoming barriers such as the lack of formal bank accounts [18][30][49]. In developing countries, they can integrate informal workers into the formal financial system, contributing to economic growth [40][49]. Furthermore, by offering basic saving and payment services at low costs, CBDCs facilitate financial inclusion for cash-reliant communities and broaden access to financial services like loans and investments [50][59].

Based on the review, it seems that the effect of CBDC depends on how it is designed. If the distribution model of the CBDC is direct, then it could lead to a competition between the central bank and commercial banks. However, in other models the central bank would act more as an issuer and maintainer of CBDC, eliminating the risk of competition with private banks.

Moreover, it is believed that the main impact of CBDC from a technological perspective will be easing the cross-border payment process, thanks to its interoperability, efficiency, and programmability. Though it should be mentioned that forming multi-CBDC agreements between central banks is essential for this [26]. In some areas with an existing infrastructure, such as countries that are members of Single Euro Payments Area (SEPA), this challenge could be relatively easier to tackle given the already existing collaboration between the central banks.

Finally, CBDC is expected to impact financial inclusion by providing access to financial services for the population in remote areas and informal workers [18][30][40][49]. Given these reasons, the effects of CBDCs are likely to be more pronounced in emerging economies than in advanced economies [49].

6.1 State of CBDC

This subsection presents a table summarizing the current state of CBDCs across various countries, based on data from the Atlantic Council's CBDC tracker [84]. The table

includes only projects that are in the launched, pilot, or cancelled stages. This selection criterion was applied because these projects are in more advanced stages of development or have been cancelled and therefore provide more comprehensive information and valuable insights. Moreover, the CBDCs in the table are ordered by the GDP of their respective countries. This approach is chosen because high GDP countries have significant economic influence beyond their borders, impacting the global economy. The GDP data is from the World Bank Group's most recent ranking [83].

Table 3 provides a comprehensive overview of these projects. There are five columns: ID, Country, Project, Stage, Motivation, Technical Design, Challenges, and References. The *ID* column represents the sequential number assigned to each entry in the table. The *Country* column denotes the country to which the respective CBDC project belongs. The *Project* column specifies the name of the CBDC project. The *Status* column shows the phase of the CBDC project and includes only those projects that have been launched, are currently in the Pilot phase, or have previously been in the Pilot phase. The *Use Case* column indicates if the CBDC is designed for Retail, Wholesale, or both use cases. The *Motivation* column describes the primary driving factors behind the initiation of the CBDC project. This field may be left empty if no specific motivation is identified. The *Technical Design* column details the technologies employed in the creation of the CBDC. This field may be left empty if there is no concrete information available. The *Challenges* column highlights the main challenges associated with the CBDC. This field may be left empty if there is no specific data available. The *Impact* column shows the impact, or expected impact of the CBDC. This field may be left empty if there is no specific data available. Finally, the *References* column lists the references that contain information about the respective CBDC project.

ID	Country	Project	Status	Use Case	Motivation	Technical Design	Challenges	Impact	References
1	China	e-CNY	Pilot	Retail	Monetary sovereignty and financial stability, Cross-border transactions, Financial inclusion, Money digitalization, Payment efficiency	Intermediated, Software Wallet, Account and Token-based	Adoption, Cybersecurity, Financial	Financial inclusion, Payment efficiency, Privacy	[35] [36] [41]
2	China, Thailand, Saudi Arabia, United Arab Emirates, Hong Kong,	mBridge	Pilot	Wholesale	Cross-border transactions	Permissioned-DLT (mBridge ledger)			[46] [47]
3	Japan	Digital Yen	Pilot	Retail	Money digitalization, Payment efficiency, Monetary sovereignty and financial stability	Account and Token-based,	Performance and scalability, Interoperability, Offline payments, Regulatory, Privacy	Monetary policy, Financial stability	[48] [51]
4	India	Digital Rupee	Pilot	Retail, Wholesale	Financial inclusion, Payment efficiency, Money digitalization, Cross-border payments	Token-based (retail version) and Account-based (wholesale version), Non-interest bearing	Technological literacy, Device accessibility, Adoption, Scalability and security	Financial inclusion, Economic growth	[18] [54] [55]
5	France, Tunisia	ProsperUs	Pilot	Wholesale	Cross-border transactions	ProsperUs DLT			[56] [57]
6	Brazil	DREX	Pilot	Retail, Wholesale	Payment efficiency, Financial inclusion, Money digitalization, Cross-border transactions	Blockchain, Hybrid model, Permissioned-DLT, Token-based	Legal risks, Privacy, Accessibility, Adoption	Financial inclusion, Monetary sovereignty, Payment efficiency, Economic boost	[61] [64]
7	Russia	Digital Ruble	Pilot	Retail, Wholesale	AML/CFT, Money digitalization, Financial inclusion, Payment efficiency, Monetary sovereignty and Financial stability	DLT-based, Hybrid model, Offline payments	Financial stability, Legal risks, Privacy risks, Performance bottlenecks	Monetary policy and Financial stability, Financial inclusion, Security	[71] [75]
8	Australia	eAUD	Pilot	Retail, Wholesale	Payment efficiency, Technological innovation	Ethereum (Quorum), Direct, Indirect, and Hybrid	Interoperability, Technological challenges, Regulatory, Adoption, Financial stability	Enhanced payment systems, Financial stability, Financial inclusion	[86] [87]
9	Australia, Singapore, Malaysia, South Africa	Project Dunbar	Pilot	Wholesale	Cross-border payments	Corda and Quorum DLTs, Azure and AWS clouds, Direct and Hybrid models, Token-based	Governance, Regulatory and Legal, Access, Technological challenges	Improved cross-border payments	[88]
10	South Korea	Digital Won	Pilot	Retail	Money digitalization	DLT, Hybrid model, Offline payments	Financial stability risks, Privacy risks, Regulatory and Compliance risks, Technological challenges	Monetary policy, Financial inclusion, Enhanced payment efficiency	[89]

Table 3. Overview of CBDC Developments by Country

ID	Country	Project	Status	Use Case	Motivation	Technical Design	Challenges	Impact	References
11	Turkiye	Digital Lira	Pilot	Retail	Financial inclusion, Money digitalization	Hardware wallet (offline payments), and Software wallet, permissioned DLT, Hybrid model	Cybersecurity, Privacy, Interoperability, Legality	Reduce banknotes, Financial inclusion	[90]
12	Saudi Arabia, United Arab Emirates	Project Aber	Pilot	Wholesale	Exploring DLT, Cross-border transactions	Decentralized-DLT (Hyperledger Fabric, Permissioned), Peer-to-Peer payments, Hybrid model, Account-based	Regulatory and Legal risks, Technological challenges (settlement finality)	Improved cross-border transactions	[91]
13	Switzerland	Project Helvetia	Pilot	Wholesale	Exploring CBDC for settlement of tokenized assets, DLT integration in financial services	Corda DLT, cloud-based infrastructure, interoperability, Hybrid model	Legal challenges, Security risks	Enhanced settlement efficiency, Financial systems innovation	[92]
14	Sweden	E-krona	Pilot	Retail	Declining cash usage, Money digitalization	R3 Corda DLT, Hybrid model, Token-based	Offline transactions, Performance challenges, Legal and Regulatory issues	Enhanced payment resilience and efficiency	[93] [94] [95] [96]
15	Thailand	Project Bang Khun Phrom	Pilot	Retail	Payment efficiency	Hybrid model, Token-based, Hardware and Software wallets, DLT and Centralized versions, Offline transactions	Offline payments, Legal and Regulatory, Double payments	Financial innovation, Enhanced payment efficiency	[97]
16	Iran	Digital Rial	Pilot	Retail	Money digitalization	Borna platform (based on Hyperledger Fabric), permissioned-DLT			[98]
17	Hong Kong	e-HKD	Pilot	Retail	Payment efficiency, Financial stability	Hybrid model, DLT-based, Account and Token-based, Offline payments, Interoperability, Software and Hardware wallets	Cybersecurity risks, Financial challenges, Legal and Regulatory challenges	Financial system, Payment efficiency	[99] [100]
18	South Africa	Project Khokha	Pilot	Wholesale	Exploring DLT applicability, Asset tokenization	R3 Corda permissioned DLT, Hybrid ledger, Hybrid model, Custodial software wallet	Cybersecurity challenges, Legality issues, Financial challenges	Financial innovation boost, Improved market efficiency	[101] [102]
19	Nigeria	e-Naira	Launched	Retail	Money digitalization, Financial inclusion, Reducing physical cash management costs, Payment efficiency	Account-based, Hyperledger Fabric permissioned DLT, Hybrid model, Custodial software wallet	Banking disintermediation risk, Cybersecurity risks, Financial exclusion	Financial inclusion, Improved financial transparency, Enhanced payment efficiency	[103] [104]
20	Kazakhstan	Digital Tenge	Pilot	Retail	Financial inclusion, Payment efficiency, Money digitalization, Financial transparency	Custodial software wallet, Hybrid model, decentralized Corda DLT, Offline payments	Cybersecurity risks, Regulatory risks, Adoption	Financial growth, Enhanced payment efficiency, Increased financial transparency	[105] [106]

Table 3. (Continued) Overview of CBDC Developments by Country

ID	Country	Project	Status	Use Case	Motivation	Technical Design	Challenges	Impact	References
21	Hungary	Digital Student Safe	Pilot	Retail	Financial inclusion, Financial literacy	Custodial software wallet, Direct model	Legal issues, Technological challenges, Adoption	Improved financial literacy, Increased financial inclusion	[107]
22	Ukraine	e-hryvnia	Pilot	Retail	Financial inclusion, Payment efficiency, Money digitalization	Custodial and non-custodial software wallet, centralized DLT based on Stellar protocol	Regulatory and Legal challenges, Financial risks, Cybersecurity challenges, Technological challenges	Enhanced financial efficiency, Increased financial inclusion, Financial stability, Disrupting existing payment ecosystem	[16] [108]
23	Uruguay	e-Peso	Pilot	Retail	Financial inclusion, Money digitalization, Reducing physical cash management costs	Custodial software wallet, Direct model, Centralized system, Offline payments	Cybersecurity challenges, Reputational challenges, Technological challenges	Enhanced payment efficiency, Increased financial inclusion	[109]
24	Ghana	E-cedi	Pilot	Retail	Modernizing payment systems, Financial inclusion, Payment efficiency	Hybrid model, Centralized ledger, Non-custodial hardware wallet (offline transactions) and Custodial software wallet (requires internet), Offline payments	Cybersecurity risks, Financial challenges	Financial inclusion, Enhanced payment efficiency, Reduced costs	[110]
25	Jamaica	JAM-DEX	Launched	Retail	Reducing physical cash management costs, Financial inclusion, Modernizing payment systems, Payment efficiency	Custodial software wallet, Hybrid model, centralized system, Offline payments	Cybersecurity risks, Legal risks, Adoption challenges	Reduced cash costs, Increased financial inclusion, Modernized financial infrastructure	[111] [112]
26	Laos	DLak	Pilot	Retail	Financial inclusion, Cross-border transactions, Monetary sovereignty, National security	Custodial software wallet, Hyperledger Iroha DLT, Hybrid model		Increased financial inclusion, Economic security	[113]
27	The Bahamas	Sand Dollar	Launched	Retail	Financial inclusion, Reducing physical cash costs, Modernizing payment systems	Custodial hardware wallet (offline payments) and Custodial software wallet (requires internet), Hybrid model, Offline payments, Centralized ledger	Financial stability risks, Cybersecurity risks, Regulatory challenges	Improved financial surveillance, Increased financial inclusion, Reduction in ill effects of cash, Reduced transaction costs	[114]
28	The Organisation of Eastern Caribbean States (OECS)	DCash	Pilot	Retail	Reducing cash usage, Financial inclusion, Payment efficiency, Economic growth	Custodial software wallets, permissioned Hyperledger Fabric blockchain hosted on Google Cloud, Hybrid model	Adoption risk, Cybersecurity risks, Merchant integration, User education	Increased financial inclusion, Economic growth, Cash usage reduction, Enhanced payment efficiency	[115] [116] [117]
29	Solomon Islands	Bokolo Cash	Pilot	Retail, Wholesale	Money digitalization, Cross-border transactions, Reducing physical cash costs, Financial inclusion	Software wallet, Hyperledger Iroha 2 (permissioned blockchain) and decentralized Substrate-based public blockchain SORA network (for cross-border transactions), Hybrid model	Governance challenges, Legal challenges	Increased financial inclusion, Secure, transparent, and reduced transactions, Improved economic resilience	[118] [119] [120]
30	Palau	Palau Stablecoin	Pilot	Retail	Financial inclusion, Reducing transaction costs, Environmental impact, Modernizing payment systems	Custodial software wallet, XRP Ledger (Decentralized blockchain), Direct model	Cybersecurity risks, Adoption challenges, Regulatory challenges, Technological infrastructure	Environmental benefits, Increased financial inclusion, Economic efficiency	[121] [122]

Table 3. (Continued) Overview of CBDC Developments by Country

7 Limitations

In this section, the limitations identified in this MLR are presented. In formulating these limitations, the guidelines for identifying, categorizing, and mitigating limitations in systematic literature reviews, as suggested by Ampatzoglou et al., were followed [123]. The following subsections detail specific limitations encountered during the research and the measures taken to address them.

One limitation of this MLR is the challenge of capturing all relevant papers. Despite extensive search strategies, there remains a risk of missing relevant studies. To mitigate this limitation, three different scientific databases—Scopus, ACM Digital Library, and IEEE Xplore—were used. Moreover, gray literature was compiled through Google. Furthermore, a comprehensive search string was crafted to cover a wide range of relevant studies. Additionally, inclusion and exclusion criteria were applied to narrow down the papers to the most relevant ones. However, this limitation could still be influenced by the exclusion of non-English papers, inaccessibility of certain papers, and other factors such as limited access to certain databases or the variability in indexing practices across databases.

Another limitation arises from the data extraction perspective. Important details might be overlooked or misinterpreted during the extraction process. Consequently, overlooked data and bias in the researcher’s data interpretation and analysis are potential causes of this limitation. To mitigate this, papers were reviewed manually, ensuring a thorough examination of each document. Additionally, data from each paper was cross-verified with data from other papers where applicable to address data inconsistencies and interpretation bias.

While this study aimed to provide a comprehensive review of the current landscape of CBDCs, acknowledging its limitations is essential for a balanced understanding of the findings. The challenges in capturing all relevant papers and ensuring accurate data extraction highlight the complexity and potential biases inherent in conducting an MLR. Despite these limitations, the measures taken to mitigate them, such as employing a broad search strategy, including gray literature, and cross-verifying data, contribute to the robustness of the study. Future research should continue to address these limitations, refining methodologies to enhance the reliability and comprehensiveness of systematic reviews in the field.

8 Conclusion

This thesis paper provides a comprehensive review of the current landscape of CBDCs. The study aimed to address four primary research questions to better understand why central banks and governments are pursuing CBDCs, the various technical approaches to their implementation, the challenges faced, and the expected impacts of their implementation.

The study employed a Multivocal Literature Review (MLR), a variation of Systematic Literature Review (SLR) which also includes gray literature, methodology to gather and analyze relevant data on CBDCs. This involved a comprehensive search and selection process to identify pertinent literature, followed by rigorous analysis to extract and synthesize key findings. The MLR process ensured that the review was thorough, unbiased, and reflective of the current state of research in the field of CBDCs.

The study discovered that the motivations for exploring CBDCs are diverse, including financial inclusion, digitalization of money, maintaining monetary sovereignty, enhancing financial stability, improving cross-border transactions, and ensuring national security. Technically, CBDCs can be designed as custodial or non-custodial wallets, account or token-based systems, and can be distributed via direct, indirect, hybrid, or intermediated models. The challenges identified span technological issues like cybersecurity and interoperability, societal factors like accessibility and public trust, financial risks such as bank disintermediation, and legal hurdles involving AML and CFT compliance. The potential impacts of CBDCs include significant shifts in monetary policy effectiveness, banking sector dynamics, technological innovation, and increased financial inclusion for underserved populations.

The paper also provides a detailed table summarizing the current state of CBDC projects across various countries according to the Atlantic Council's CBDC tracker. The table includes columns for the ID, country, project, status, use case, motivation, technical design, challenges, impact and references, offering a comprehensive overview of CBDC projects in launched and pilot stages. This table serves as a valuable reference for future researchers and central banks interested in the development and implementation of CBDCs. During this study, the need for further research in the CBDC field was identified. Future studies should focus on several key areas: documenting the development of pilot projects as they progress to mature stages, with attention to successes, challenges, and lessons learned; exploring CBDCs from a UI/UX perspective to understand user interactions, ease of use, accessibility, and overall satisfaction; conducting localized studies to address the unique motivations and challenges faced by individual countries, tailoring CBDC solutions to meet local needs; and assessing the long-term economic effects of CBDCs on monetary policy, banking sector dynamics, and overall financial stability as they transition from pilot to full-scale implementation.

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