

Research Article**Central Bank Digital Currencies vs. Bitcoin: Competing or Complementary Digital Currencies?****Brahmaleen K. Sidhu¹**

Dept. of Computer Science and Engineering, Punjabi University, Patiala, India

Corresponding Authors: **Received:** 09/Feb/2025; **Accepted:** 10/Mar/2025; **Published:** 30/Apr/2025. **DOI:** <https://doi.org/10.26438/ijcse/v13i4.2333> Copyright © 2025 by author(s). This is an Open Access article distributed under the terms of the [Creative Commons Attribution 4.0 International License](#) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited & its authors credited.

Abstract: With the rapid digitization of finance, Central Bank Digital Currencies (CBDCs) and Bitcoin represent two distinct approaches to digital money. CBDCs are state-backed and regulated, whereas Bitcoin is decentralized and independent of government control. Understanding their interaction is crucial for policymakers, economists, and investors. This paper conducts a comprehensive SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis of both CBDCs and Bitcoin to evaluate their impact on the global financial landscape. The study explores the fundamental differences between these digital currencies, covering aspects such as monetary control, technological frameworks, regulatory challenges, and economic implications. The paper begins with an overview of related work, detailing various forms of money and existing comparative studies between CBDCs and Bitcoin. It then examines the structure, benefits, risks, and development of CBDCs, followed by an in-depth discussion on Bitcoin, including blockchain architecture, cryptographic protocols, and consensus mechanisms. Through a systematic SWOT analysis, the strengths of CBDCs—such as financial inclusion and transaction efficiency—are contrasted with their weaknesses, including privacy concerns and implementation costs. Similarly, Bitcoin's decentralized nature and transparency are weighed against its volatility and regulatory uncertainty. Findings from this study highlight the need for balanced regulatory frameworks and technological innovations to maximize the benefits of both CBDCs and Bitcoin while mitigating associated risks. These insights contribute to ongoing discussions on the role of digital currencies in shaping the future of finance. The paper concludes with future research directions, emphasizing the importance of interoperability, scalability, and evolving security measures in the digital currency ecosystem. This research article will contribute to the ongoing debate on digital currencies, providing a balanced perspective on whether CBDCs and Bitcoin are rivals or complementary elements in the evolving financial landscape.

Keywords: Bitcoin, Blockchain, Central Bank Digital Currency, Cryptocurrency, Decentralized Finance, Digital Currencies, Fiat-backed Digital Currency, Financial Inclusion

1. Introduction

With the rapid evolution of digital payments, it is crucial to analyse the role of Central Bank Digital Currencies (CBDCs) and Bitcoin in the global financial ecosystem. CBDCs are government-backed digital currencies aiming to modernize the financial system, while Bitcoin is a decentralized asset often referred to as 'digital gold'. This study explores whether they are rivals or can coexist in a complementary manner.

This paper discusses various aspects of this digital currency innovation, such as financial stability, monetary policy implications, privacy, security, and financial inclusion. CBDCs provide governments with better monetary control, allowing central banks to implement policies such as negative

interest rates. Bitcoin, on the other hand, operates outside traditional financial institutions and is resistant to inflation due to its fixed supply of 21 million coins. Understanding how these two systems interact is essential for policymakers, financial institutions, and investors. CBDCs could allow governments to track transactions, raising questions about financial surveillance. Bitcoin offers pseudonymity, but its transparency on the blockchain can still expose user data. While Bitcoin's decentralized nature reduces the risk of centralized failure, CBDCs could be vulnerable to cyberattacks and misuse. CBDCs can improve access to banking services for unbanked populations, whereas Bitcoin provides an alternative financial system independent of government control. Understanding these dynamics is vital to predict the future of banking and digital payments.

Countries are grappling with how to regulate Bitcoin while simultaneously exploring CBDCs. Central banks worldwide are actively conducting pilot programs and research initiatives to assess the feasibility and potential benefits of implementing CBDCs within their economies. As of September 2024, three countries—The Bahamas, Jamaica, and Nigeria—have successfully launched fully operational CBDCs. Meanwhile, the Eastern Caribbean Currency Union temporarily suspended its CBDC due to technical challenges and has since initiated a new pilot program. Currently, 44 CBDC pilots are in progress globally, with eight G20 nations developing their own initiatives.

Additionally, the BRICS nations—Brazil, Russia, India, China, and South Africa—are actively exploring CBDCs to modernize their financial infrastructures (<https://www.atlanticcouncil.org/cbdctracker/>). Not all CBDC projects have been successful. One notable example is the United Kingdom's Britcoin, which was introduced in 2011 but discontinued in 2019. In the United States, the Federal Reserve continues to evaluate whether a CBDC could enhance the efficiency and security of the existing domestic payment system, though no final decision has been made.

This paper contributes to the evolving discourse on digital currencies by offering a comparative analysis of CBDCs and Bitcoin in terms of their origin, governance, technological frameworks, and economic implications. It highlights how CBDCs and Bitcoin reflect contrasting paradigms—centralized vs. decentralized—while also exploring scenarios where both could coexist within the financial ecosystem. By synthesizing regulatory, technical, and philosophical perspectives, the paper provides valuable insights for policymakers, economists, and technologists seeking to understand the potential for cooperation or conflict between these two forms of digital money.

The rest of the paper is organized as follows: Section 1 presents the introduction, outlining the significance of digital currencies and their impact on financial systems. Section 2 provides a review of related work, discussing various forms of money and comparative studies between CBDCs and Bitcoin. Section 3 delves into the foundational concepts of CBDCs and Bitcoin. Section 4 presents the research methodology adopted in the study. Section 5 discusses the results and section 6 concludes the study, summarizing key insights and discussing future research directions.

2. Related Work

This section reviews existing research on CBDCs and Bitcoin, examining their technological foundations, economic implications, regulatory challenges, and potential coexistence in the financial ecosystem. Prior studies have explored the advantages and limitations of both forms of digital currency, but the interplay between state-backed and decentralized digital assets remains an evolving area of research.

2.1 Forms of Money

Understanding the landscape of modern money requires distinguishing between established forms and emerging digital assets. Traditional monetary systems primarily revolve around central bank money and commercial bank money. Central bank money, the bedrock of the financial system, is issued by entities like the Federal Reserve, encompassing physical currency and digital reserves held by commercial banks. This form is considered the safest, carrying neither credit nor liquidity risk. Commercial bank money, the digital currency most commonly used by the public, resides in accounts at commercial banks. It benefits from safeguards like federal deposit insurance, minimizing risk. Alongside these, nonbank money, held with financial service providers, offers digital convenience but carries higher risk due to fewer protective measures.

In contrast to these established forms, CBDCs represent a digital evolution of central bank money. A CBDC would be a digital liability of a central bank, designed to function as a secure and readily accessible form of electronic money. This innovation aims to combine the safety of central bank money with the efficiency of digital transactions. Therefore CBDC's would fall under the category of central bank money. This is a key difference from other digital forms of money, and would be a direct liability of the central bank.

Bitcoin, on the other hand, operates outside the traditional financial framework. As a decentralized cryptocurrency, it exists independently of central banks and traditional financial institutions. Bitcoin's value is determined by market forces and its underlying technology, rather than government backing. It is neither central bank money, commercial bank money, or nonbank money. This fundamental distinction highlights the divergence between regulated, institutional money and decentralized, digital assets.

2.2 Comparative Studies Between CBDCs and Bitcoin

Laboure et al. examine the evolving landscape of cryptocurrencies and CBDCs, assessing their future roles and potential impact. The study explores the key socio-economic and historical drivers behind digital currency adoption while evaluating cryptocurrency as an investment within diversified portfolios. The study also considers the environmental, social, and governance implications of digital currencies, highlighting concerns and opportunities. Lastly, it reviews the progress of national CBDC projects and discusses their potential influence on the broader digital currency ecosystem once they are officially launched [1].

Bernhart's bachelor thesis [2] examines the comparative dynamics between CBDCs and stablecoins, exploring potential overlaps and their economic, technological, and legal implications. Using the PESTLE framework, the study assesses key political, economic, and social factors influencing digital currency adoption. The research incorporates expert interviews and secondary data to provide insights into the evolving role of CBDCs and stablecoins in global finance. Due to limited real-world CBDC

implementations, it remains uncertain whether retail, wholesale, or hybrid models will dominate.

While stablecoins are already widely used, their viability depends on the broader crypto market and traditional financial systems. Algorithmic stablecoins attempt to replicate central bank mechanisms, yet their success remains unproven. Despite stability issues, backed stablecoins have gained traction, even though they contradict cryptocurrency's decentralized ethos. The paper argues that stablecoins and CBDCs will likely coexist, serving different purposes for different users based on risk profiles and needs.

CBDCs provide legal security and institutional backing, while stablecoins offer greater flexibility and innovation. The two models differ fundamentally, as stablecoins are liabilities of private issuers, whereas CBDCs remain under central bank control. The possibility of integrating both systems through blockchain, distributed ledger technology (DLT), and financial innovations presents new opportunities. Future regulatory developments will determine whether governments opt for stricter controls or collaborative frameworks. Ultimately, the expansion of CBDCs and stablecoins signals a transformative shift in global financial ecosystems.

Jozipović et al. examine the legal framework governing national virtual currencies and CBDCs through a comparative legal lens [3]. Their paper explores the definitions of 'means of payment' and 'legal tender', analysing the legal implications of classifying specific payment methods under these terms. The study further investigates recent advancements in sovereign virtual currencies, comparing the regulatory approaches of various national digital currencies. Key case studies include developments in several African nations, Venezuela's introduction of a state-backed crypto token, early CBDC pilot programs in Uruguay and China, and discussions on a potential CBDC within the European Union. Based on these analyses, the paper highlights critical legal challenges such as privacy concerns, user protection, and transaction regulation, particularly in the context of establishing a functional national or supranational euro CBDC.

A report by UN Taskforce series on Global Digital Finance Governance [4] explores the macroeconomic impacts and regulatory challenges of CBDCs and other digital currency initiatives in developing countries. It acknowledges the evolving nature of digital currencies and regulations, analyzing various forms, including stablecoins and earlier digital money, to assess their economic effects and emerging regulatory gaps. The paper examines mobile money and e-money, highlighting their role in financial inclusion while addressing concerns about market dominance and regulatory challenges posed by Big Fintech (BFT) companies. It evaluates stablecoins, particularly global ones like the proposed Diem, in relation to existing payment systems, emphasizing their limited advantages for developing economies. A focused analysis of CBDCs considers their potential macroeconomic implications for Least Developed Countries (LDCs), with examples from pilot projects and

launched digital currencies. The paper also discusses Africa's role as a hub for financial inclusion technologies, the impact of the COVID-19 pandemic, and global shadow banking concerns. The study concludes by highlighting risks such as fragmented regulations, emerging governance structures, and gaps between national fiscal policies and technological capabilities, offering insights into governance innovations to mitigate risks and vulnerabilities in LDCs.

A study by Hamm et al. [5] develops a digital currency adoption model, separately assessing cryptocurrencies, stablecoins, and CBDCs. A large-scale user study involving 785 German respondents, representative of the working-age population, evaluates these models through a multigroup analysis. Results indicate that adoption across all three currency types is primarily driven by self-efficacy and trust, while risk factors have little influence. Notably, CBDCs receive higher trust and self-efficacy scores, suggesting a greater willingness to adopt them compared to private digital currencies. These findings highlight the promising adoption potential of CBDCs, as they benefit from stronger public confidence than cryptocurrencies and stablecoins. The study also demonstrates how multigroup analysis can effectively compare the adoption processes of different financial technologies, provided equivalent model items are identified for each currency type. Ultimately, this research offers insights into the future of digital currency adoption, emphasizing the role of trust and perceived usability in shaping public acceptance.

While prior research has extensively explored the individual roles of CBDCs and Bitcoin, limited studies have examined their competitive or complementary nature in shaping the future of digital finance. This study aims to bridge that gap by analysing their coexistence, competition, and impact on financial markets.

3. Theory

3.1 Objectives of Central Bank Digital Currencies

A CBDC is a form of digital money issued and regulated by a nation's central bank. Unlike cryptocurrencies, its value is tied to the country's official fiat currency. Fiat money, traditionally in the form of banknotes and coins, is government-issued and not backed by a physical commodity such as gold or silver; it functions as legal tender for the exchange of goods and services. With technological advancements, many governments and financial institutions have introduced digital systems to complement physical currency by electronically tracking balances and transactions. In several developed nations, the use of physical cash has declined, a shift further accelerated by the COVID-19 pandemic.

The rise of cryptocurrency and blockchain technology has further fuelled interest in cashless societies and digital currencies. As discussed in the introduction section, numerous countries are actively developing CBDCs, with some already implementing them. As global interest in digital currencies continues to grow, understanding CBDCs and their

societal impact is becoming increasingly important. The primary objectives of CBDCs are:

1. To offer businesses and consumers a secure, private, accessible, and convenient means of conducting financial transactions.
2. To lower the costs associated with maintaining a complex financial system, reduce cross-border transaction fees, and provide more affordable alternatives to existing money transfer methods.
3. To mitigate the risks associated with cryptocurrencies, which are highly volatile and can pose financial instability for households and the broader economy. As government-backed digital currencies, CBDCs provide a stable and reliable medium of exchange.
4. To equip central banks with tools to implement monetary policies that promote economic stability, control growth, and manage inflation effectively.

3.2 Types of CBDC

CBDCs are categorized into two main types: wholesale and retail. Wholesale CBDCs are primarily used by financial institutions, while retail CBDCs are designed for consumers and businesses. Both types of CBDCs can coexist within the same financial system, providing flexibility in digital currency adoption.

Wholesale CBDCs operate similarly to central bank reserves. Financial institutions are granted accounts at the central bank to deposit funds or facilitate interbank transfers. Central banks can leverage monetary policy tools, such as reserve requirements and interest rates on reserves, to regulate lending and influence economic stability.

Retail CBDCs are digital currencies issued by the government for public use. They eliminate intermediary risk, ensuring that private digital currency issuers cannot go bankrupt and lose customer funds. Retail CBDCs come in two forms, differing in access and transaction methods: (a) Token-based retail CBDCs use private and public key encryption, allowing users to make transactions anonymously. (b) Account-based retail CBDCs require digital identification for access.

3.3 Potential Benefits of a CBDC

A CBDC could serve as a secure foundation for the modern payment system, ensuring financial stability in a rapidly digitizing economy. By providing risk-free digital money accessible to the public, a CBDC could support private-sector innovation while mitigating risks associated with private digital currencies like stablecoins and cryptocurrencies. Unlike cash, which allows anonymous transactions, a CBDC would require compliance measures to prevent illicit financial activities.

A CBDC could also foster a more competitive and inclusive financial landscape by enabling smaller firms to innovate without the high costs and risks of issuing private digital currency. Additionally, programmable CBDCs could enhance transaction efficiency, enabling scheduled payments and facilitating micropayments, which are difficult for traditional payment systems.

In the realm of cross-border payments, a CBDC could introduce simplified distribution channels and enhance global financial collaboration, though international coordination on standards, legal frameworks, and security measures would be essential.

Another significant benefit is maintaining the U.S. dollar's global dominance. Given the widespread international use of the dollar in payments and investments, a U.S. CBDC could help sustain its role as the world's primary reserve currency amid the rise of foreign digital currencies.

A CBDC could also improve financial inclusion, reducing barriers for economically vulnerable populations by lowering transaction costs and expanding access to digital banking services. Finally, as cash usage declines, a CBDC could provide the public with continued access to secure, government-backed money in digital form.

3.4 Potential Risks of CBDC

While a CBDC offers potential benefits, it also raises significant policy concerns and risks that require further research and analysis.

1. Impact on Financial Markets: A CBDC could reshape the financial sector by altering the roles of banks and the central bank. Since banks rely on deposits to fund loans, a widely used CBDC—especially one that offers interest—could reduce bank deposits, increasing funding costs and potentially limiting credit availability. Similarly, a shift away from low-risk assets like Treasury bills and money market funds could impact businesses and government borrowing. Design choices, such as a non-interest-bearing CBDC or limiting account balances, could help mitigate these effects.
2. Financial Stability Risks: During economic stress, a CBDC could encourage rapid withdrawal of deposits from commercial banks, intensifying bank runs and destabilizing the financial system. Traditional safety measures like deposit insurance might be insufficient to counteract large-scale fund transfers into CBDC. Setting withdrawal limits or restricting short-term accumulation could reduce this risk, but the fundamental challenge of deposit substitution remains.
3. Monetary Policy Implications: A CBDC could influence the Federal Reserve's ability to implement monetary policy. If CBDC demand fluctuates significantly, it could impact the supply of bank reserves and interest rate control. An interest-bearing CBDC could further complicate monetary policy by shifting funds from bank deposits and other low-risk investments. Additionally, foreign demand for CBDC could introduce further complexity. The Federal Reserve may need to expand its balance sheet to accommodate these shifts.
4. Privacy, Security, and Financial Crime Prevention: Balancing consumer privacy with regulatory transparency is a key challenge. An intermediated CBDC model involving private financial institutions could help address privacy concerns while ensuring compliance with anti-money laundering and anti-terrorism financing

regulations. However, strong cybersecurity measures would be crucial, as a CBDC network could have more access points and be vulnerable to sophisticated cyberattacks.

5. Operational Resilience: A CBDC must be highly resilient to cyber threats and operational disruptions. One possible advantage is offline functionality, allowing transactions during natural disasters or internet outages. Central banks are currently exploring the feasibility of such a feature.

Overall, careful design choices and policy considerations will be critical in ensuring a CBDC strengthens rather than disrupts the financial system.

3.5 CBDCs in Use and in Development

The Atlantic Council, a nonpartisan think tank based in Washington, D.C., focused on international affairs and global security, reported in September 2024 that 134 countries and currency unions, accounting for 98% of global GDP, are actively exploring the potential implementation of CBDCs (c.f. Figure 1). This marks a significant increase from just 35 countries in May 2020. 66 countries have progressed to advanced stages of CBDC development, including phases such as development, pilot testing, or full-scale deployment. Among the G20 nations, all 20 are engaged in CBDC research, with 19 in advanced stages and 13—such as Brazil, Japan, India, Australia, Russia, and Turkey—currently in the pilot phase. Three nations—the Bahamas, Jamaica, and Nigeria—have successfully launched fully functional CBDCs. In Nigeria and the Bahamas, adoption rates have surged, and efforts are underway in all three countries to expand the domestic use of their retail CBDCs.

Globally, the number of ongoing CBDC pilot programs has reached a record 44, including the digital euro. European countries, both within and beyond the Eurozone, are intensifying their wholesale CBDC testing, focusing on domestic and cross-border applications. All five original BRICS nations—Brazil, Russia, India, China, and South Africa—are piloting CBDCs, with the bloc actively pushing for an alternative payments system that reduces reliance on the U.S. dollar. In nations with advanced retail CBDC projects, distribution is intermediated, meaning banks, financial institutions, and payment service providers facilitate issuance and transactions. The U.S. has joined Project Agorá, a cross-border wholesale CBDC initiative involving six other central banks. However, in May 2024, the U.S. House of Representatives passed a bill prohibiting the Federal Reserve from directly issuing a retail CBDC, though the Senate has yet to take action. The debate over CBDC policy remains a key issue in the ongoing U.S. presidential campaign.

Since Russia's invasion of Ukraine and subsequent G7 sanctions, cross-border wholesale CBDC projects have doubled, now totalling 13 initiatives. Among them is Project mBridge, which links banks in China, Thailand, the UAE, Hong Kong, and Saudi Arabia, with potential expansion to more countries this year. China's digital yuan (e-CNY) remains the largest CBDC pilot globally. As of June 2024, e-CNY transactions surpassed 7 trillion yuan (\$986 billion)

across 17 provinces, spanning sectors such as education, healthcare, and tourism. This represents nearly a fourfold increase from June 2023, when transactions totalled 1.8 trillion yuan (\$253 billion), as reported by the People's Bank of China.

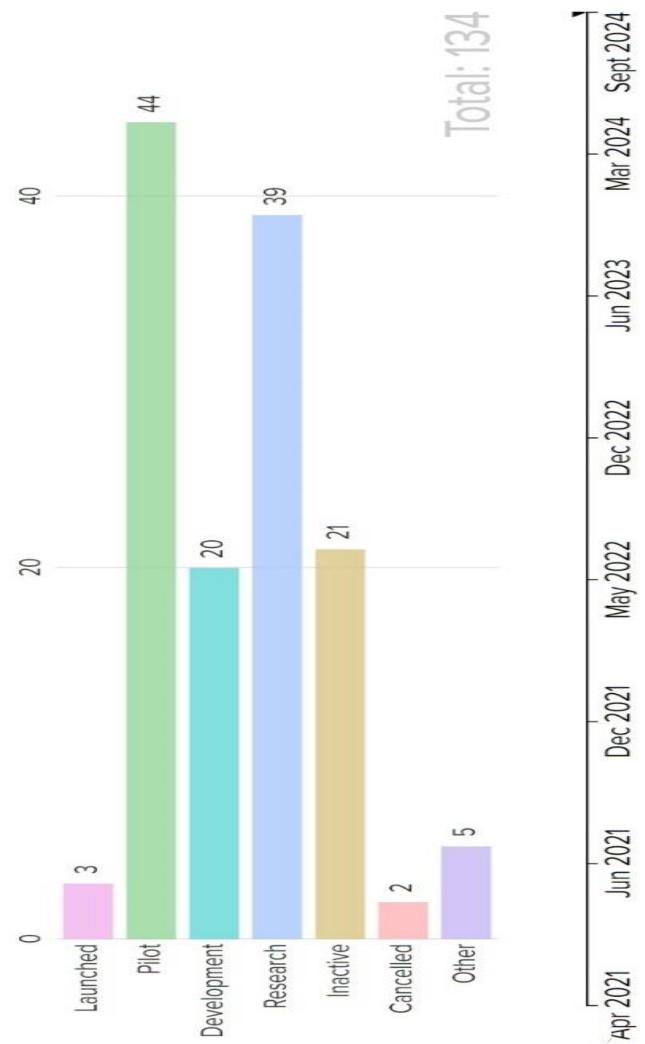


Figure 1. Number of countries and currency unions exploring CBDC over time (source: <https://www.atlanticcouncil.org/cbdctracker>)

3.6 Key Features of Bitcoin

Introduced by Satoshi Nakamoto in 2008 [6], Bitcoin is a peer-to-peer electronic cash system built on three fundamental components: miners, the blockchain, and wallets. Miners play a crucial role in validating transactions, preventing double-spending through the proof-of-work consensus mechanism, and ensuring sufficient funds and digital signatures. The blockchain, a distributed ledger, provides a transparent and immutable record of all transactions across the network. Wallets, secured by private keys, enable users to access and manage their Bitcoin holdings. Bitcoin achieves privacy through pseudonymity, where public keys are anonymous, while transaction amounts and timestamps are publicly visible. From a user perspective, Bitcoin is nothing more than a mobile app or computer program that provides a personal Bitcoin wallet and allows a user to send and receive bitcoins with them.

Bitcoin can be obtained through exchanges, as payment for goods or services, or by participating in the mining process. Bitcoin's design incorporates several key features that distinguish it from traditional financial systems:

1. Decentralization: Bitcoin operates on a peer-to-peer network, meaning it's not controlled by any single entity, such as a government or bank. This distributed nature enhances its resilience and reduces the risk of censorship.
2. Blockchain Technology: The blockchain is a public, distributed ledger that records every Bitcoin transaction. This technology ensures transparency and immutability, as each block of transactions is linked to the previous one, forming a secure chain.
3. Limited Supply: Bitcoin's protocol dictates a maximum supply of 21 million coins. This scarcity is a core feature, designed to prevent inflation and potentially increase its value over time.
4. Mining: Mining is the process of verifying and adding transactions to the blockchain. Miners use computational power to solve complex mathematical problems, and in return, they receive newly minted Bitcoin. This process secures the network and maintains its integrity.
5. Pseudonymity: While Bitcoin transactions are recorded on the public blockchain, they are not directly linked to individuals' real-world identities. Instead, transactions are associated with pseudonymous addresses, providing a degree of privacy.
6. Peer-to-Peer Transactions: Bitcoin enables direct transactions between users, without the need for intermediaries like banks. This can lead to faster and lower-cost transactions, particularly for cross-border payments.
7. Censorship Resistance: Because of the decentralized nature of the network, it is very difficult for any single entity to censor or block Bitcoin transactions.

These features contribute to Bitcoin's unique characteristics and its role as a pioneering cryptocurrency.

3.7 Blockchain

Satoshi Nakamoto invented blockchain technology in 2008 with the creation of Bitcoin. The technology allowed for direct online payments between people, without a need for banks. Blockchain brings trust to peer-to-peer network solutions. The primary reason that banks have been in existence for decades is that they act as a trusted third party in a transaction. Blockchain can operate in a peer-to-peer fashion with zero intervention from third parties. Thus, it eliminates the need for trust while conducting business.

Blockchain is fundamentally a decentralized ledger that records all transactions within a peer-to-peer network. Originally developed as the underlying technology for Bitcoin, it has since found applications across various business domains. Beyond facilitating transactions, blockchain also safeguards user anonymity and ensures high levels of security. At its essence, it consists of a sequence of blocks—each block containing digital information—linked together in a public database known as the chain.

Types of Blockchain

Blockchains can be broadly classified into two types: permissionless (public) blockchains and permissioned blockchains, which include private and consortium blockchains. While they share features like peer-to-peer networking, transaction timestamping, and immutability, they differ in their consensus mechanisms and the number of participating nodes.

Public blockchains are permissionless, meaning anyone can publish, read, or download blocks without needing approval from a central authority. These networks are highly decentralized but may face challenges related to performance, privacy, and security. Bitcoin and Ethereum are the most well-known public blockchains.

Consortium (or federated) blockchains operate under the control of a group of organizations, where each organization runs a node, and new participants require approval from existing members. While they are less decentralized than public blockchains, they offer improved performance and efficiency.

Private blockchains are fully permissioned and centralized, managed by a single organization that controls participation, consensus execution, and ledger maintenance. This structure enhances trust, security, and performance but requires users to rely on the integrity of the controlling entity.

Permissioned blockchains offer greater control, transparency, and accountability. These networks facilitate continuous auditing and decision-making, ensuring that misbehaving parties are held accountable. However, trust in the governing entity remains a crucial factor in their adoption.

3.8 Cryptographic Protocols

Blockchain functions as a continuously expanding sequence of blocks, each serving as a digital ledger that builds upon its predecessor. Every block contains a unique identifier known as a hash, which cryptographically links it to the previous block. This interconnection ensures immutability, as any alteration in a block would disrupt the entire chain, signalling possible tampering.

A widely used cryptographic hash function in blockchain systems is SHA-256 (Secure Hash Algorithm-256). It generates a fixed 256-bit output (digest) from any input, ensuring data integrity and security [7]. A key property of SHA-256 is collision resistance, meaning it is computationally infeasible for two different inputs to produce the same hash.

The SHA-256 algorithm offers 2^{256} ($\approx 10^{77}$) possible hash values, making the likelihood of a collision—where $\text{hash}(x) = \text{hash}(y)$ —theoretically possible but practically negligible. This robust cryptographic structure enhances blockchain security, ensuring the integrity of transactions and preventing fraudulent alterations.

3.9 Consensus Models

A core aspect of blockchain technology is determining which participant will add the next block, a process governed by a consensus mechanism. In permissionless blockchain networks, multiple nodes compete to publish new blocks, often incentivized by rewards such as cryptocurrency or transaction fees. Users joining a blockchain network accept its initial state, recorded in the first block, known as the genesis block. This block is publicly available, and subsequent blocks must follow a sequential order based on the consensus model. Regardless of the mechanism used, each block undergoes independent validation by network participants, eliminating the need for a trusted third party. For a block to be added, all nodes must gradually reach a common agreement.

In permissioned blockchain networks, where nodes share a certain level of trust, computationally intensive consensus mechanisms are often unnecessary. As trust increases, the need for resource-heavy verification decreases. These networks use consensus mechanisms not only for block validation but also for comprehensive checks throughout the transaction process, from proposal to final inclusion.

Proof of Work

The Proof of Work (PoW) model, used by Bitcoin, requires the publishing node to solve a complex computational puzzle before adding a block to the chain. While solving this puzzle is difficult, verifying the solution is straightforward for other nodes, ensuring only valid blocks are accepted. A common approach in PoW involves adjusting the target hash value, requiring it to have a certain number of leading zeros [8]. This difficulty adjustment helps regulate Bitcoin's block creation rate to approximately one block every ten minutes, aligning computational demands with network security as computing power evolves.

Proof of Stake

The Proof of Stake (PoS) model selects block publishers based on the amount of cryptocurrency they have staked (locked) in the network. Since users with a higher stake have a vested interest in maintaining the system's integrity, they are more likely to act honestly. Unlike PoW, PoS eliminates the need for resource-intensive computations, making it significantly more energy-efficient. In some PoS networks, rather than creating new cryptocurrency as a reward, block publishers earn transaction fees as incentives.

Both PoW and PoS aim to achieve secure, decentralized consensus, but they differ in efficiency, energy consumption, and security approaches, influencing the choice of model for different blockchain applications.

3.10 Current State of Bitcoin

Bitcoin has maintained its position as the leading decentralized digital asset in 2024, with increasing institutional adoption, evolving regulatory frameworks, and the emergence of Layer 2 solutions aimed at improving scalability.

Institutional Adoption and Market Trends

Institutional interest in Bitcoin has surged significantly, with corporations and financial institutions holding approximately 683,332 BTC, which is around 3.3% of the total supply. This represents a staggering 587% increase since 2020. The increasing recognition of Bitcoin as a strategic asset rather than just a speculative investment has contributed to its growing adoption, with an annual adoption rate of around 40%. The launch of Bitcoin ETFs has been another major milestone, attracting over \$5.4 billion in inflows in October 2024 alone. BlackRock's iShares Bitcoin Trust ETF has led the charge, reflecting growing confidence in Bitcoin among mainstream financial institutions [9].

Scalability and Layer 2 Solutions

Bitcoin has historically faced challenges regarding transaction speed and scalability. However, several Layer 2 solutions have emerged to address these issues. Babylon is leveraging optimistic rollups to boost transaction throughput while reducing fees, making Bitcoin more practical for decentralized finance applications. Meanwhile, Stacks enables smart contracts and decentralized applications (dApps) on Bitcoin, allowing for tokenized assets and new financial instruments without modifying the core Bitcoin protocol. CoreDAO introduces a hybrid consensus mechanism that combines Bitcoin's Proof-of-Work security with Delegated Proof-of-Stake scalability, facilitating faster and cheaper transactions.

Regulatory Landscape

Governments worldwide are refining their regulatory approaches to Bitcoin. The U.S. and Europe are leading in crafting frameworks that balance innovation with consumer protection. Bitcoin mining regulations are also evolving, with growing pressure on miners to adopt more sustainable practices.

Price Forecast and Future Outlook

Analysts remain optimistic about Bitcoin's price trajectory, with forecasts suggesting potential price targets between \$102,000 and \$140,000 by mid-2025. This optimism is driven by historical patterns following Bitcoin's halving events, increased institutional involvement, and improvements in scalability through Layer 2 solutions.

4. Research Methodology

This study employs a qualitative, comparative analysis methodology grounded in a review of existing literature, policy reports, pilot programs, and real-world implementations of CBDCs and Bitcoin. The research is exploratory in nature and aims to synthesize insights across technological, economic, regulatory, and social dimensions to understand whether CBDCs and Bitcoin are fundamentally competing or can exist as complementary instruments within the digital financial landscape.

The methodological flowchart shown in figure 2 outlines a structured approach beginning with defining research objectives, conducting a literature review, and collecting

secondary data from credible sources like central banks and crypto networks. It then proceeds through comparative and SWOT analyses, leading to interpretation, results, and policy recommendations, ultimately concluding with future research directions. Primary data sources include official publications from central banks, international financial institutions such as the IMF and BIS, white papers, and publicly available statistics on CBDC pilot programs. For Bitcoin, the study examines academic literature, blockchain technical documentation, cryptocurrency research, and market reports.

The research is structured around several thematic pillars: financial stability, monetary policy impact, privacy and surveillance concerns, cybersecurity, and financial inclusion. These dimensions form the basis of a comparative framework used to evaluate the strengths, limitations, and real-world implications of both CBDCs and Bitcoin. In addition, a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis is conducted separately for CBDCs and Bitcoin to offer a structured evaluation of each system's strategic positioning in the evolving financial ecosystem.

The methodology emphasizes a multidisciplinary lens, drawing from economics, computer science, finance, and public policy to provide a holistic understanding of the two digital currency paradigms. The findings are interpretative rather than statistical, and the goal is to foster deeper understanding and informed discourse among stakeholders, rather than to test a specific hypothesis.

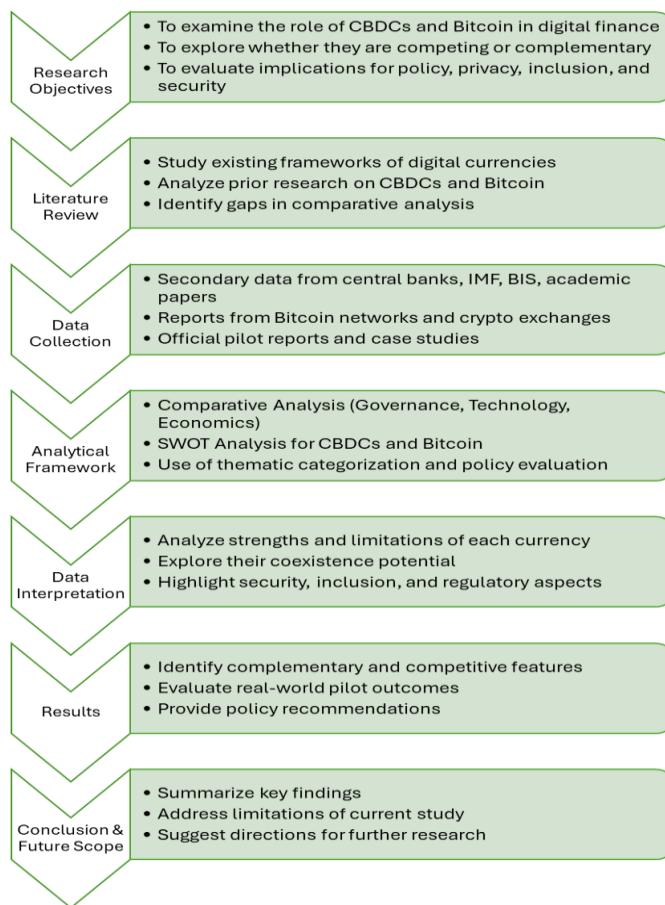


Figure 2. Research methodology flowchart

5. Results and Discussion

This section presents the key findings of the study, followed by an in-depth discussion of their implications in the context of existing literature and ongoing developments in the digital currency landscape.

5.1 SWOT Analysis of CBDC

This section presents a SWOT analysis of CBDC, evaluating its potential benefits, limitations, opportunities for global financial systems, and associated risks. Understanding these factors is crucial for policymakers, financial institutions, and consumers as they navigate the evolving digital economy.

Strengths

1. Financial Inclusion: CBDCs can provide banking access to unbanked and underbanked populations, enabling financial participation in regions with limited banking infrastructure.
2. Security and Trust: As a government-backed digital currency, CBDCs offer a secure alternative to cryptocurrencies and private digital payment solutions.
3. Reduced Transaction Costs: Digital transactions through CBDCs eliminate intermediaries, reducing costs associated with cash handling, ATM services, and payment processing fees.
4. Monetary Policy Efficiency: CBDCs provide central banks with a direct tool to implement monetary policies, including setting interest rates and controlling money supply more effectively.
5. Transparency and Anti-Fraud Measures: With CBDCs utilizing blockchain or centralized ledger technologies, transactions become more transparent, reducing risks of fraud, corruption, and illicit activities.
6. Resilience Against Economic Crises: CBDCs can enhance economic stability by ensuring seamless transactions and reducing reliance on cash during crises like pandemics or financial collapses.

Weaknesses

1. Technological and Infrastructure Challenges: Implementation of a CBDC requires robust digital infrastructure, cybersecurity frameworks, and nationwide internet penetration, which may be lacking in some economies.
2. Privacy Concerns: The level of government control over CBDC transactions may lead to privacy violations and surveillance concerns among citizens.
3. Risk of Disintermediation: If consumers switch entirely to CBDCs, commercial banks may suffer from lower deposit levels, potentially reducing their lending capacity.
4. Implementation Costs: Developing and maintaining a secure CBDC system requires significant investment in technology, regulatory frameworks, and cybersecurity measures.
5. Cross-Border Compatibility Issues: Different countries may adopt varying technological frameworks and policies for CBDCs, complicating international transactions.

Opportunities

1. Digital Economy Growth: CBDCs can accelerate the shift toward digital economies, enhancing payment efficiency and financial innovation.
2. Reduction in Counterfeiting: Digital currencies eliminate risks associated with counterfeit banknotes and cash-related fraud.
3. Enhanced Cross-Border Transactions: CBDCs can simplify international payments, reducing delays and costs associated with traditional banking systems.
4. Potential for Programmable Money: Smart contract integration with CBDCs can enable conditional transactions, automated taxation, and real-time settlements.
5. Public-Private Collaboration: Central banks can partner with fintech companies to drive innovation in CBDC applications and enhance user experiences.
6. Emergency Relief and Direct Transfers: Governments can use CBDCs for direct economic stimulus payments, reducing inefficiencies in social welfare programs.

Threats

1. Cybersecurity Risks: CBDCs are vulnerable to cyberattacks, hacking, and system failures, which can undermine public confidence and financial stability.
2. Geopolitical Concerns: Rivalries between major economies over digital currency dominance could lead to global financial fragmentation.
3. Public Resistance and Trust Issues: Citizens may resist CBDC adoption due to privacy concerns, fear of government control, or preference for cash transactions.
4. Potential Bank Runs: If CBDCs provide higher security and accessibility than traditional bank deposits, consumers may shift funds from commercial banks, leading to liquidity risks.
5. Regulatory and Legal Hurdles: Implementing a CBDC requires overhauling existing financial regulations, which can be complex and time-consuming.
6. Impact on Traditional Banking System: The reduced role of commercial banks in deposit collection and lending could disrupt financial markets and economic stability.

5.2 SWOT Analysis of Bitcoin

Bitcoin, the first and most widely used cryptocurrency, has disrupted traditional financial systems with its decentralized and borderless nature. However, it faces various opportunities and challenges that influence its adoption and future growth. The SWOT analysis presented in this section provides a comprehensive evaluation of Bitcoin's position in the financial landscape.

Strengths

1. Decentralization: Bitcoin operates on a decentralized network, reducing reliance on central banks and financial institutions.
2. Security & Immutability: Transactions on the Bitcoin blockchain are irreversible and secured by cryptographic mechanisms, minimizing fraud risks.

3. Limited Supply: With a cap of 21 million coins, Bitcoin is often compared to digital gold, providing a hedge against inflation.
4. Borderless Transactions: Bitcoin enables cross-border transactions without the need for intermediaries, reducing costs and processing time.
5. Financial Inclusion: It offers banking services to the unbanked population by providing access to a decentralized financial system.

Weaknesses

1. Volatility: Bitcoin's price fluctuates significantly, making it unreliable as a stable store of value or medium of exchange.
2. Scalability Issues: The Bitcoin network faces transaction speed and cost limitations, which may hinder widespread adoption.
3. Energy Consumption: Bitcoin mining is energy-intensive, raising environmental concerns and regulatory scrutiny.
4. Lack of Consumer Protection: Transactions are irreversible, meaning users have no recourse if they fall victim to fraud or mistakes.
5. Regulatory Uncertainty: Governments worldwide continue to develop laws around Bitcoin, leading to uncertainty for investors and businesses.

Opportunities

1. Mainstream Adoption: More businesses and institutions are integrating Bitcoin as a payment and investment option.
2. Institutional Investment: Large financial firms and hedge funds are increasingly investing in Bitcoin, adding legitimacy to the asset.
3. Technological Advancements: Innovations like the Lightning Network aim to improve Bitcoin's scalability and transaction efficiency.
4. Inflation Hedge: As fiat currencies face inflationary pressures, Bitcoin is becoming an alternative store of value.
5. Global Remittances: Bitcoin offers a low-cost alternative for cross-border remittances, especially in countries with weak financial infrastructure.

Threats

1. Regulatory Crackdowns: Governments may impose restrictions or bans on Bitcoin, affecting its usability and adoption.
2. Competition from Other Cryptocurrencies: Alternatives like Ethereum and CBDCs may reduce Bitcoin's dominance in the crypto market.
3. Cybersecurity Risks: While blockchain is secure, exchanges and wallets are vulnerable to hacks and thefts.
4. Market Manipulation: Bitcoin's relatively low liquidity compared to traditional assets makes it susceptible to price manipulation.
5. Quantum Computing Threats: Future advancements in quantum computing may pose risks to Bitcoin's cryptographic security.

5.3 Discussion

Table 1 outlines a comprehensive comparison between two major forms of digital currencies, emphasizing their contrasting characteristics, functionalities, and objectives.

CBDCs are issued and regulated by central banks, making them official legal tender backed by a nation's monetary authority. In contrast, Bitcoin is a decentralized digital currency that operates independently of any government or central institution, and while it is not legal tender in most jurisdictions, it is widely traded and accepted in the global crypto economy.

CBDCs are closely aligned with a country's monetary policy and enable governments to influence money supply, interest rates, and financial stability. Bitcoin, however, functions outside traditional monetary systems, following a fixed supply cap of 21 million coins, making it immune to inflationary manipulation but also more volatile in terms of price. The transaction mechanisms also differ: CBDCs typically use centralized ledgers with oversight by government institutions, whereas Bitcoin operates on a decentralized blockchain, with transactions validated through an energy-intensive Proof of Work consensus mechanism. This gives Bitcoin high transparency and immutability, but at the cost of greater energy consumption.

When it comes to user identity and regulatory compliance, CBDCs are designed to enforce Know Your Customer (KYC) and Anti-Money Laundering (AML) rules, ensuring traceability of transactions. Bitcoin, by design, is pseudonymous, allowing users to transact through cryptographic addresses without directly revealing personal identities. In terms of price behavior, CBDCs offer the stability of traditional fiat currency, whereas Bitcoin's value is highly volatile and influenced by market dynamics, often being used as a store of value or speculative asset.

CBDCs are intended to modernize traditional cash systems, promote financial inclusion, and improve payment efficiency. Bitcoin, on the other hand, positions itself as a decentralized alternative to the banking system, offering financial sovereignty and protection against centralized control. Additionally, CBDCs are typically more energy-efficient due to centralized infrastructure, while Bitcoin's security model consumes significantly more energy.

From a technical perspective, CBDCs are expected to support programmability, allowing for conditional payments and smart contracts. Bitcoin's base layer has limited programmability, though advanced features can be accessed via Layer 2 solutions. Lastly, CBDCs are generally designed for domestic use with limited cross-border capability, while Bitcoin is inherently global and borderless in nature.

In summary, CBDCs and Bitcoin represent two fundamentally different approaches to digital currency. CBDCs are state-controlled tools for improving and regulating national financial systems, while Bitcoin offers a decentralized and alternative financial network. Whether they will coexist as complementary forces or compete for dominance in the future digital economy remains an open question, largely dependent on technological development, regulatory policies, and public trust.

Table 1. Comparison between CBDCs and Bitcoin

Aspect	CBDCs	Bitcoin
Issuing Authority	Central banks (e.g., RBI, ECB, Fed)	Decentralized; no central authority
Legal Status	Legal tender backed by the government	Not legal tender in most countries
Monetary Policy	Aligned with central bank's monetary policy	Independent of any monetary policy
Transaction Validation	Centralized ledger maintained by the issuing authority	Decentralized consensus (Proof of Work)
Transparency	Varies by design (can be fully transparent or private)	Public ledger; fully transparent
Anonymity	Limited or no anonymity (Know Your Customer - KYC - compliance)	Pseudonymous (not fully anonymous)
Price Stability	Stable; pegged to fiat currency	Highly volatile; driven by market demand and supply
Purpose	Digital alternative to cash; financial inclusion; efficiency in payments	Store of value, speculative investment, alternative to traditional finance
Energy Consumption	Low (centralized systems)	High (due to mining and Proof of Work consensus)
Programmability	High potential for programmable features (e.g., smart contracts)	Limited programmability; some through second-layer solutions
Adoption Scope	Domestic and regulated cross-border transactions	Global and permissionless adoption
Security	Centralized security infrastructure	Cryptographic, blockchain-based security

6. Conclusion and Future Scope

CBDCs and Bitcoin represent two contrasting approaches to digital currency—one centralized and regulated by governments, the other decentralized and independent of traditional financial systems. The SWOT analysis highlights that CBDCs offer enhanced financial inclusion, security, and monetary policy control, but face challenges such as high implementation costs, privacy concerns, and potential disruptions to banking institutions. On the other hand, Bitcoin provides financial autonomy, transparency, and borderless transactions, yet struggles with volatility, scalability, and regulatory scrutiny.

The coexistence of these digital currencies could shape the future of financial ecosystems, with CBDCs addressing institutional stability and financial governance, while Bitcoin and other cryptocurrencies drive innovation and financial sovereignty. Moving forward, regulatory frameworks, technological advancements, and evolving user preferences will play a crucial role in determining their long-term adoption and impact on global economies. A balanced approach that harnesses the strengths of both systems while mitigating risks can lead to a more inclusive and efficient financial landscape.

The future of CBDCs and Bitcoin presents vast opportunities for research, innovation, and policy development. As digital currencies gain global traction, advancements in security, regulatory frameworks, and financial stability mechanisms will be crucial. Strengthening cybersecurity measures, particularly through quantum-resistant encryption and AI-driven fraud detection, will be vital to safeguarding digital transactions. The regulatory landscape will also evolve, requiring policymakers to strike a balance between financial privacy and compliance, ensuring seamless cross-border transactions while mitigating risks such as illicit activities and financial surveillance. Additionally, the economic implications of widespread CBDC adoption need further study, particularly its impact on traditional banking systems, financial inclusion, and monetary policy.

Bitcoin's role as digital gold and a decentralized financial instrument is expected to expand, with ongoing enhancements in scalability solutions like the Lightning Network and innovations in sustainable mining practices to address environmental concerns. The integration of emerging technologies such as artificial intelligence, decentralized finance, and the Internet of Things (IoT) will further shape the digital currency ecosystem, enabling automated transactions and enhancing financial efficiency. Future research should also explore the socio-economic impact of these digital assets, particularly in developing economies where access to traditional banking remains limited. As digital currencies continue to evolve, their success will depend on collaborative efforts between governments, financial institutions, and technological innovators to ensure a secure, inclusive, and sustainable financial future.

6.1 Future Scope

The future scope of research on CBDCs and Bitcoin lies in exploring their evolving roles in global finance. As CBDCs progress toward implementation, studies can assess their impact on monetary policy, financial inclusion, and payment systems. Simultaneously, Bitcoin's use as a decentralized asset and technological upgrades offer insights into its potential complementarity with CBDCs. Future research should also examine regulatory frameworks, privacy concerns, and user adoption. Interdisciplinary studies can further analyse societal perceptions and the balance between centralized control and decentralization. Together, these explorations will shape the future of digital currencies in a rapidly transforming financial landscape.

Data Availability: None.

Conflict of Interest

Author declares that there is no conflict of interest regarding this research.

Funding Source: None.

Authors' Contributions

The author conceptualized the research idea, conducted the literature review, performed comparative analysis, and wrote the manuscript.

Acknowledgements

The author expresses sincere gratitude to peers and reviewers who provided valuable feedback during various stages of the paper. Special thanks to the institutions and online resources that offered access to relevant data and literature.

References

- [1] M. Laboure, M. H.-P. Müller, G. Heinz, S. Singh and S. Köhling, "Cryptocurrencies and CBDC: The Route Ahead," *Global Policy*, Vol.12, pp.663-676, 2021.
- [2] S. Bernhart, "Applications of CBDCs and private stablecoins: Comparative analysis," *Northwestern Switzerland*, 2020.
- [3] Š. Jozipović, M. Perkušić and N. Mladinić, "A Comparative Review of the Legal Status of National Cryptocurrencies and CBDCs: A Legal Tender or Just Another Means of Payment," *Pravni vjesnik: časopis za pravne i društvene znanosti Pravnog fakulteta Sveučilišta J.J. Strossmayera u Osijeku*, Vol.40, No.1, pp.77-96, 2024.
- [4] F. Katherine, S. Blakstad, S. Gazi and M. Bos, "Digital Currencies and CBDC Impacts on Least Developed Countries (LDCs)," *United Nations Development Programme and United Nations Capital Development Fund*, 2021.
- [5] P. Hamm, F. Tronnier and D. Harborth, "Can the Digital Euro Succeed where Bitcoin Failed? A Multigroup Comparison of Adoption Intention in Digital Currencies in Germany," *Pacific Asia Journal of the Association for Information Systems*, Vol.17, No.1, pp.82-109, 2025.
- [6] S. Nakamoto, *Bitcoin: A Peer-to-Peer Electronic Cash System*, 2008.
- [7] S. Z. Ali, D. Sahu and J. Sahu, "Bitcoin in Blockchain: A Survey," *International Journal of Computer Sciences and Engineering*, Vol.7, No.6, pp.708-712, 2019.
- [8] D. W. Walumbe and J. G. Ndia, "A Systematic Literature Review of Proof of Work and Proof of Activity: Privacy and Performance," *International Journal of Computer Sciences and Engineering*, Vol.11, No.10, pp.37-44, 2023.
- [9] J. Campbell and V. Puri, "State of Bitcoin: 2024," 17 December 2024.

AUTHOR'S PROFILE

Dr. Brahmaleen K. Sidhu holds a Ph.D. in Engineering and Technology from Punjabi University, Punjab, India, an M.Tech. in Computer Science and Engineering from Punjab Technical University, and a B.Tech. in the same field from Punjabi University. She currently serves as an Assistant Professor in the Department of Computer Science and Engineering at Punjabi University and brings nearly 19 years of teaching experience. Her research interests span software architecture, software evolution, software quality, refactoring, model-driven development, data science, and machine learning. She has authored around 90 research papers published in reputed international journals indexed in SCI and Web of Science, as well as in IEEE conferences. In 2023, she published a book titled "A Handbook of Reinforcement Learning." Dr. Sidhu received the "International Innovative Educator Award 2021" and was recognized among the "100 Eminent Academicians of 2021" by the International Institute of Organized Research.

