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Crypto ecosystem: navigating the past, present, and future of decentralized finance

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Abstract
From Nakamoto's genesis block, 15 years of technological advancements, new financial instruments, regulations, and emerging participants have defined the Crypto Ecosystem. This paper chronicles its development from the creation of Bitcoin to the present-day landscape of cryptocurrencies, tokens, and decentralized finance applications. It explores the foundational technologies, financial instruments, key players, and regulatory frameworks in Europe and the US. By critically assessing the current state of the crypto market, the paper identifies both the promises fulfilled and the challenges that remain. It contributes to the existing literature by providing a synthesized understanding of the crypto ecosystem, highlighting the interplay between technological advancements and financial market dynamics.

Keywords Digital finance · Blockchain · Crypto · Cryptocurrency · DeFi

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1 Introduction

The term "cryptocurrency" derives from the fusion of "cryptography" and "currency," with cryptography rooted in ancient Greek terminology denoting hidden or secret writing systems. This nomenclature reflects the core principle of these digital assets: the utilization of advanced encryption techniques to secure financial transactions without the need for intermediaries. The inception of what scholars now term the "Digital Currency Era" can be traced to January 11, 2009. On this date, computer scientist Hal Finney initiated a significant technological advancement by activating a specialized computer node, marking the commencement of the Bitcoin network. Finney's succinct announcement on the social media platform Twitter—"Running Bitcoin"—garnered substantial attention within technological circles. Contemporaneously, an enigmatic figure known by the pseudonym Satoshi Nakamoto orchestrated the creation of the inaugural set of Bitcoin units, colloquially referred to as the "genesis block" (Nakamoto, 2008). This confluence of events—Finney's node activation and Nakamoto's genesis block—heralded the dawn of a new financial paradigm that continues to challenge traditional economic structures, regulatory frameworks, and investment strategies.

The innovative aspect of Bitcoin lies in its integration of several technological and conceptual elements: a decentralized peer-to-peer network, a novel consensus mechanism termed "Proof of Work," and the groundbreaking concept of a "blockchain"—a distributed ledger technology. These components coalesce to form a system of decentralized governance, diverging significantly from traditional centralized financial institutions. The impetus behind this technological revolution can be traced to a community of privacy-focused technologists and developers. Their motivation stemmed from a desire to address perceived shortcomings in centralized financial systems, particularly in light of the global financial crisis of 2007–2008 (Villanueva, 2024). In the decade and a half since Bitcoin's inception, a diverse ecosystem of digital currencies has proliferated. This includes alternative cryptocurrencies (e.g., Dogecoin, Ripple, Ethereum), digital assets pegged to traditional currencies (known as "stablecoins," e.g., Tether), and various types of digital tokens (e.g., EOS, Polkadot). Concurrently, new economic actors have emerged, including specialized computer operators ("miners"), software developers, digital currency exchanges, and investors in these novel assets. This rapid expansion and diversification of the digital currency landscape have precipitated calls for new regulatory frameworks. These aim to establish a secure ecosystem for participants while simultaneously addressing the radical shift in content ownership and control that these technologies enable.

The advent of cryptocurrencies represents a significant paradigm shift from conventional monetary frameworks, introducing innovative concepts of decentralized governance, enhanced security protocols, and increased individual autonomy in financial transactions. As this nascent field continues to evolve, it presents both opportunities and challenges for established economic structures and regulatory bodies. This new era in financial technology has facilitated the development of a disintermediated approach to managing monetary resources, commonly referred to as Decentralized Finance (DeFi) (Harvey et al., 2021; Bank for International Settlements, 2023; Financial Stability Board, 2023; Financial Services Institute, 2023; Momtaz, 2024). DeFi is an umbrella term encompassing "a set of alternative financial markets, products, and systems that operate using crypto-assets and smart contracts (software) built on a distributed ledger or similar technology" (Financial

Stability Board, 2023, p. 42). This emerging sector represents a rapidly expanding segment of the digital asset ecosystem. Its primary objective is to circumvent traditional financial intermediaries by providing analogous services—such as lending and borrowing facilities, investment opportunities, and the exchange of digital assets—without relying on conventional centralized intermediaries and market infrastructures. These novel applications harness network effects by recombining financial products and services, facilitating connections between investors, and progressively capturing market share from traditional financial ecosystems.

The disintermediation facilitated by these systems represents a fundamental shift in how financial transactions and services are conceptualized and executed. By removing centralized authorities and intermediaries from financial processes, these systems aim to increase efficiency, reduce costs, and provide greater financial autonomy to individuals. However, it is important to note that while these systems offer potential benefits, they also present new challenges. These include issues of regulatory compliance, security concerns, and the need for new frameworks to govern these decentralized systems. As this field continues to develop, it necessitates ongoing research, dialogue, and potentially new policy approaches to ensure its integration into broader economic systems in a manner that balances innovation with stability and consumer protection.

This article contributes to the understanding of the Crypto ecosystem by identifying the enabling technologies, newly emerged financial instruments, key players involved, regulatory landscapes, and the crypto ideology's inherent risks, trade-offs and unfulfilled promises. While extant literature has highlighted the potential of digital assets in supporting economic activities, facilitating market access for enterprises, and promoting financial inclusion (e.g., Butticè & Vismara, 2022; Cumming et al., 2021; Harvey et al., 2021; Meoli & Vismara, 2021), our research provides a more nuanced examination of the evolving market dynamics, underscored by its significant growth trajectory and accompanying public interest. Building upon recent scholarly contributions in the fields of Decentralized Finance (e.g., Harvey et al., 2021; Schär, 2021), digital assets (e.g., Bellavitis et al., 2022, 2023; Benedetti & Kostovetsky, 2021; Fisch & Momtaz, 2020; Momtaz, 2024), and cryptocurrency (e.g., Arner et al., 2024; De Filippi & Loveluck, 2016; Villanueva, 2024; Zetzsche et al., 2020), this article presents a comprehensive analysis of Bitcoin and other digital assets. As a result of the events of the last sixteen years, our research contributes to the existing body of knowledge by offering a holistic perspective on the digital asset landscape, synthesizing insights from multiple disciplines (i.e., financial, regulatory and technological) to provide a more complete understanding of this complex and rapidly evolving field.

The remainder of the paper is structured as follows: Sect. 2 introduces the technology underlying the decentralized infrastructure. Section 3 introduces the technology, the instruments, and the participants in the crypto ecosystem. Section 4 identifies relevant regulatory frameworks, and Sect. 5 evaluates the crypto ideology. Section 6 concludes.

2 The crypto ecosystem

This Section is structured into several sub-sections that delineate various components and processes within the cryptocurrency domain.

First (Sect. 2.1), we begin with an overview of foundational technologies, including Distributed Ledger Technology (DLT), which underpins blockchain and other crypto innovations. Within this segment, DLT's operational mechanics, such as cryptographic signatures and redundancy, are detailed, leading to an exploration of blockchain technology, which employs a consensus algorithm and hashing to ensure data integrity. The discussion transitions to smart contracts, emphasizing their self-executing nature and evolving use cases. Second (Sect. 2.2), we categorize crypto assets into distinct types, such as cryptocurrencies, stablecoins, security tokens, utility tokens, and non-fungible tokens (NFTs), providing definitions and regulatory perspectives on each. Third (Sect. 2.3), we address the mechanisms of issuing and trading crypto assets, with a focus on Initial Coin Offerings (ICOs), Initial Exchange Offerings (IEOs), and Initial DEX Offerings (IDOs), and their impact on the market. Fourth (Sect. 2.4), we examine centralized and decentralized exchanges, highlighting their functions, regulatory challenges, and market dynamics. Finally (Sect. 2.5), we present the players in the crypto ecosystem, including miners, core developers, investors, and Decentralized Autonomous Organizations (DAOs), detailing their roles, influences, and the evolving nature of their contributions within the crypto landscape. This structured approach facilitates a comprehensive understanding of the multifaceted nature of the crypto ecosystem and its various operational and regulatory aspects.

2.1 The backbone technology

2.1.1 Distributed ledger technology (DLT)

DLT facilitates transactions' storage, processing, and validation within a peer-to-peer decentralized network, eliminating the need for intermediaries. DLT can disrupt traditional systems of registering, sharing, and synchronizing transactions on digital assets by operating without a central authority. It enhances efficiency and transparency due to its tamper-resistant and censorship-resistant qualities, commonly called immutability (Harvey et al., 2021).

From a technological perspective, DLT is a replicated ledger across network nodes, recording, tracking, and authenticating every transaction with a unique cryptographic signature. Cryptography should use a single secret key for both encryption and decryption (symmetric key cryptography, SKC) or separate keys for encryption and decryption (asymmetric key cryptography, AKC). The latter involves using a public/private key scheme, where the sender digitally signs the message's encryption using their unique private key, and the decryption is then verified by the receiver with the digital signature using the sender's public key (McGurk & Reichenbach, 2024). In the AKC, the private key must remain confidential, while the public key can be shared with others; however, knowing the public key does not compromise the security of the private key since it relies on the difficulty of solving a mathematical problem. Cryptocurrencies like Bitcoin, for instance, rely on Elliptic Curve Cryptography (ECC), an example of AKC, to secure transactions and wallets. ECC proves cryptocurrency ownership, maintaining transaction pseudonymity (it is possible to track the identity of the sender), integrity (the ability to detect possible data theft and attack), and non-repudiation through the use of digital signatures (the ability to prove that a specific party has sent a message).

However, some technological challenges, such as the advent of quantum computing and energy-intense system design problems, pose risks to AKC. New quantum algorithms expo-

nentially speed up solving mathematical problems and have the potential to easily bypass encryption methods, developing more efficient attacks to uncover secret keys. While cryptocurrencies are not in immediate danger, the crypto ecosystem will require infrastructure upgrades to develop quantum-resistance cryptographic solutions and remain secure.

2.1.2 Blockchain

Blockchain, a type of DLT invented in 1991 by Haber and Stornetta for time-stamping document versions, uses a unique data format distributed among network nodes, recording data in blocks linked through a hashing process, thus ensuring immutability (FSB, 2023). Each blockchain block is created via a consensus algorithm, a set of rules that establish what blocks can become part of the chain and should be considered "verified"; hence, all participants agree on the content, and only trusted nodes can add new information.

Blockchain applications include cryptocurrencies, such as Bitcoin and Ethereum, which operate on a decentralized and permissionless model, ensuring secure transactions without a central authority but incurring high energy costs. Many consensus algorithms have been introduced, but two are the most known and used: Proof-of-Work (PoW) and Proof-of-Stake (PoS). PoW involves validators competing to solve cryptographic puzzles, demanding significant computational power and electricity. At the same time, PoS selects participants based on the number of coins they stake, addressing environmental and scalability concerns. In 2022, Ethereum moved from a proof-of-work to a proof-of-stake mechanism, reducing the Ethereum blockchain's energy usage by 99%.

Ethereum co-founder Vitalik Buterin highlights the inherent challenge for blockchain technology to simultaneously achieve three critical aspects: security, scalability (the ability to handle a large volume of transactions quickly and efficiently), and decentralization. This means that blockchain developers often have to choose between these three trade-offs when building blockchain architectures. For example, Bitcoin is highly decentralized, and PoW allows for high security, but its design makes scalability challenging. New solutions have emerged to address the scalability limitations while maintaining security and decentralization. They refer to Layer 2 of blockchain architectures[1], which aims to boost transaction efficiency (improving the number of transactions that can be processed per second and reducing cost, i.e., gas fees) without compromising the decentralization and security of the chain. Thus, the blockchain trilemma simultaneously prompts competition and innovation within the crypto ecosystem. On one side, the blockchain trilemma creates competition between different crypto technologies where different projects prioritize different aspects to differentiate themselves; on the other, the trilemma fosters innovation as developers explore various solutions to offer superior performance and user experience

Blockchain technology is expected to have many far-reaching effects on entrepreneurship and entrepreneurial activity (Spigarelli et al., 2024), especially in vulnerable ecosys-

[1] Blockchain architectures are composed of hierarchical layers associated to different functions and opportunities: Layer 0, Layer 1, Layer 2, and Layer 3. Layer 0, such as Cosmos and Cardano, refers to all software and hardware that constitute blockchain foundations. The goal of Layer 0, is to make blockchain networks functional, accessible, and interoperable thus, integrates with other networks. Layer 1, such as Bitcoin and Ethereum, use Layer 0 infrastructures for transactions and present own structure, including consensus mechanisms, ledger systems, coding language, and own tokens. Layer 2 are built on top of Layer 1 to improve efficiency or scalability. Finally, Layer 3, such as Uniswap, adds apps (DApps) to create applicable user experience. They range from cryptocurrency wallets to decentralized exchanges.

tems (Rawhouser et al., 2024). In essence, both DLT and blockchains enable tracking and recording transactions with assured data integrity, facilitated by a distributed network, asymmetric encryption, and Merkle tree structures, offering various levels of innovation based on their configuration.

2.1.3 Smart contracts

Smart contracts are self-executing codes that initiate actions when predefined conditions are met, facilitating functionalities such as conditional payments. Proposed by Nick Szabo in the 1990s and significantly advanced with the introduction of Ethereum (ETH) by Vitalik Buterin in 2014, smart contracts have revolutionized crypto applications by replacing traditional financial infrastructures and offering greater value to a wider user base. These contracts allow predefined conditions to control spending, manage assets and data, and define interactions between network participants without a trusted third party. Execution costs vary based on the code's complexity and the data exchanged and stored. Essential components of smart contracts include oracles, which provide real-time external data (e.g., weather, news) to smart contracts, and bridges, which enable interoperability between blockchains by creating synthetic tokens that represent assets from one blockchain on another. Despite their utility, bridges can be targets for attacks due to the large amounts of crypto-assets they manage (FSB, 2023). The market for smart contracts is expected to grow from US$1.9 billion in 2023 to US$9.2 billion by 2032, with North America, the UK, and Germany leading in adoption. Beyond blockchain and crypto industries, smart contracts are gaining interest in public and retail sectors, where governments can use them to transfer property documents and manage identity information securely, and supply chain management can benefit from transparent and tamper-proof records of product information, including origin, quality, and movement.

2.2 Crypto assets

Crypto assets (or tokens) represent one of the major applications of blockchain technology, encompassing valuable digital or virtual items such as digital tokens and non-fungible tokens (NFTs) (Corbet et al., 2019). These assets are created, stored, and traded on digital platforms like Decentralized Exchanges (DEX), allowing them to be bought, sold, or traded similarly to traditional assets. Following the advent of Bitcoin, blockchain and DLT systems have been utilized to develop thousands of crypto-assets with diverse characteristics. Building on Nakamoto's model, various projects have adopted this technology to register currencies and digital content. Stablecoins have become particularly significant, designed to address cryptocurrency volatility by anchoring to a basket of reference assets.

Currently, there is no universal definition of crypto assets. Our study covers the main categories of crypto assets as identified by international authorities (FSB, BIS, ESMA): cryptocurrencies, stablecoins, security and utility tokens. Additionally, it will address non-fungible tokens (NFTs), which differ from fungible tokens by representing unique assets like artwork or ownership deeds (e.g., Crypto-Kitties) (Lee et al., 2020).

Indeed, the EU's Market in Crypto-assets Regulation (MiCAR) is the first legislative effort trying to define crypto assets as a «digital representation of a value or of a right that can be transferred and stored electronically using distributed ledger technology or similar

technology» (art. 3, par.1, n. 5, Reg. EU 2023/114). Various taxonomies of crypto assets exist, differing on the basis of the purpose of analysis—whether legal, technical, or functional—which complicates cross-country policy and regulatory comparisons (FSI, 2023). Nevertheless, there is consensus on three key characteristics: creation by private individuals using sophisticated technology, storage in electronic wallets (e-wallets) rather than physical possession, and acquisition through platform exchanges, user transfers, or mining rewards.

Since 2018, European authorities (ESMA, 2019) have highlighted the need to differentiate between cryptocurrencies like bitcoin, mined within distributed, public and permissionless networks and other tokens primarily issued through ICOs (e.g., non-native tokens issued at the app level instead of protocol level and tied to specific projects or platforms). The key reasons for this distinction lay in differences in functionality (used as a medium of exchange/store of value versus granting access to services/products or financial rights), regulatory implications (cryptocurrencies are typically not considered securities, while ICO tokens, depending on their design, may be classified as securities, which subjects them to stricter regulatory requirements under European law), market maturity and associated risks (cryptocurrencies are volatile but less susceptible to fraud in established networks, while tokens can be subject to higher risks of frauds given the unproven nature of their underlying projects). ICO tokens garnered attention from EU authorities, who, adhering to technological neutrality (Mattassoglio, 2018), began classifying them under existing legislation as securities (Markets in Financial Instruments Directive II), electronic money (Electronic Money Directive), or payment instruments (Payment Services Directive 2).

2.2.1 Cryptocurrencies

This category encompasses virtual currencies such as Bitcoin (BTC) and Ether, defined by the ECB (2012) as "a type of unregulated digital currency, issued and usually controlled by its developers, and used and accepted among members of a specific virtual community." Bitcoin, the most prominent cryptocurrency, is often debated regarding its validity as a true currency (payment instrument, unit of account, store of value). Launched presumably by Satoshi Nakamoto, an alleged identity, in 2008 as a reaction to the traditional financial system's failures, Bitcoin operates without a central issuer or intermediary, relying on a consensus mechanism based on cryptography (Bellezza, 2019). The term Bitcoin derives from "Bit," the unit of information in computing representing either 1 or 0, and "Coin" as a digital currency. Together, "Bitcoin" suggests the idea of a digital currency based on cryptographic principles and technology. This system, which eliminates the need for centralized transaction validation, proposes an alternative to traditional banking, promoting governance without government intervention (De Filippi & Loveluck, 2016). Critics, however, argue that Bitcoin has evolved into a speculative asset, diverging from its original ideals of social justice and financial disintermediation.

2.2.2 Stablecoins

Stablecoins are crypto-assets designed to maintain a stable value by being pegged to specific assets (e.g., fiat currency, gold) or a basket of assets. They can be classified based on three main characteristics: the existence of an issuer, the type of technology (permissioned or permissionless), and the stabilization mechanism (tokenized funds, collateralized stable-

coins, or algorithmic stablecoins). Tokenized funds, or fiat-backed stablecoins, stabilize value through linkage to fiat currency and rely on an issuer for redeemability. Collateralized stablecoins are tied to assets that may fluctuate in value, with risks varying between off-chain (physical) and on-chain (digital) assets. Algorithmic stablecoins use algorithms and smart contracts to maintain stability without collateral, as seen in TerraUSD[2]. Initially overlooked by regulators, stablecoins gained attention with Facebook's Libra project, leading to increased regulatory scrutiny and recommendations from the Financial Stability Board (FSB, 2020) to ensure financial stability.

2.2.3 Security tokens

Security tokens are DLT-based assets that confer rights and obligations similar to traditional financial instruments like shares or debt. They transform buyers into investors, offering interest or dividends, and are regulated as securities in many jurisdictions.

2.2.4 Utility tokens

Utility tokens are a crypto-asset that provides access to a good or service offered by the issuer rather than functioning as securities. They are excluded from financial instrument regulations and lack stabilization mechanisms, making them distinct in their purpose. Utility tokens grant holders the right to use a specific product or service, potentially positioning them outside the scope of traditional financial regulation. This exclusionary definition underscores their role in granting access rather than investment, distinguishing them from other crypto-asset categories.

2.2.5 Non-fungible tokens (NFTs)

NFTs are unique digital assets representing ownership of specific items such as art and collectibles. Unlike fungible crypto-assets, NFTs are not interchangeable, with their value derived from individual characteristics. The NFT market is projected to reach US$2,378 million in revenue by 2024, driven by growing interest in digital art and collectibles, exemplified by projects like Chromie Squiggle and marketplaces like OpenSea. Despite their tradability, NFTs are unique, making value comparison challenging. The EU regulator emphasizes that NFTs cannot be readily compared or valued against existing markets due to their distinct nature (Reg. 2023/1114).

2.2.6 What is not a crypto asset: central bank digital currencies (CBDC)

Central bank digital currencies (CBDCs) are issued directly by central banks and represent their direct liabilities as cash (Nabilou, 2020). Consequently, public digital currencies do not respect two of the three conditions to be considered cryptocurrencies i.e., privately issued,

[2] Terra was an algorithmic stablecoin designed to be pegged to various fiat currencies, leading to the creation of fiat-based stablecoins such as TerraUSD (UST), TerraEUR, and TerraKRW. In May 2022, Terra experienced a liquidity crisis following an attack on its liquidity pools, which led to its collapse and wiped out an estimated $60 billion from the digital currency market. For more details, see Briola et al. (2023).

stored in electronic wallets, acquired through platform exchanges, user transfers, or mining rewards.

CBDCs can be categorized into two primary types: "general purpose" or "retail" CBDCs, accessible to all users and functioning as a digital equivalent of cash, and "wholesale" CBDCs, intended for specific financial institutions, akin to central bank reserves. According to the Forum's Central Bank Digital Currency Global Interoperability Principles white paper, wholesale CBDCs resemble reserve accounts held by commercial banks with central banks but have the potential to enhance cross-border payments and securities transactions. The technology underpinning CBDCs allows for various designs tailored to specific purposes and interests, resulting in considerable heterogeneity. For instance, the Chinese "Digital Yuan," the Bahamian "Sand Dollar," the Nigerian "E-Naira," and the Swedish "E-Krona" exhibit significant design and technological differences. Each CBDC's unique characteristics necessitate careful consideration, especially regarding privacy, the role of commercial banks, and the definition of "legal currency." Thus, generalizations about CBDCs can lead instead to uncertainties and misunderstandings.

2.3 Issuing and trading crypto assets

ICOs are a crowdsourced fundraising method for launching new tokens, coins, and services. Adhami et al. (2018) describe ICOs as open calls for funding, where companies raise money in exchange for tokens. This process typically includes a pre-sale of crypto assets, a defined maximum (hard-cap) or minimum (soft-cap) funding amount, and a white paper detailing the project, team founders, and token characteristics (Belitski & Boreiko, 2022). Tokens can be categorized as 'utility tokens,' granting rights to use company products or services, or 'security tokens,' which provide the buyer with investment returns, such as interest or dividends. When ICOs involve security tokens, they are referred to as Security Token Offerings (STOs), akin to traditional Initial Public Offerings (IPOs) (Ritter et al., 2013; Bongini et al., 2022; Fisch et al., 2021). Token ownership is secured through cryptography and DLT, allowing tokens to be claimed on the issuer, typically listed on specialized exchanges shortly after the ICO, thus creating a secondary market. The first ICO was launched by MasterCoin in 2013, and soon the ICO market became global (Huang et al., 2020), with significant activity beginning at the end of 2016 and peaking between 2017 and 2019, raising over US$31 billion (Bellavitis et al., 2021, 2022). However, ICO activity declined sharply in 2021, also because of widespread fraud, a lack of regulatory oversight, and reduced investor trust (Hornuf et al., 2021).

ICOs have been supplemented by Initial Exchange Offerings (IEOs) and Initial DEX Offerings (IDOs). In IEOs, a centralized exchange (CEX) partners with the project and organizes the token sale, while in IDOs, a third-party platform manages the sale, with tokens immediately listed on a decentralized exchange (DEX). IEOs involve intermediaries, such as CEX, ensuring compliance with Know Your Customer (KYC) and Anti-Money Laundering (AML) regulations, providing investor protection. Instead, IDOs do not involve intermediaries and belong to the DeFi phenomenon. They can offer companies several advantages, including shorter durations, faster listings, and better early-stage performance though, at present, they constitute a challenge for regulators (see more in detail Sect. 3). IDOs are emerging as promising fundraising methods for crypto ventures, depending on a company's objectives and methods, as they address issues inherent to ICOs, such as the lack

of an exchange managing the campaign or token liquidity, thus reducing offering-related risks. Conversely, IEOs tend to perform better in long-term trading than IDOs (Sun and Young, 2024).

2.4 Centralized and decentralized exchanges

Crypto asset exchanges have emerged as dominant financial institutions in the crypto economy, offering various services beyond trading (Gulieva, 2024). These services include issuing stablecoins, offering custodial and payment services, lending funds to borrowers in exchange for interest payments (crypto-lending), crypto stacking (a type of leverage through contracts whose settlement is deferred, with crypto-assets as underlying or margin), crypto staking services (the lock-up of crypto-assets to support the operations of proof-of-stake blockchain consensus mechanisms in return for a reward).

Exchanges can be categorized into CEX and DEX. CEXs, such as Binance, Coinbase, and Upbit, present an infrastructure similar to that observed in the traditional equities market. Due to their multiple activities—acting as trading venues, broker-dealers, and lenders—CEXs function as key intermediaries (Dell'Erba, 2023). Users keep custody of the assets in the CEX's collective wallet, taking the risk of having difficulties getting them back. CEXs operate with an order-book-based system, which allows users to trade cryptocurrencies against traditional fiat currencies. In DEXs, like Uniswap, PancakeSwap, and SushiSwap, users have control over their private keys and assets thanks to the Automated Market Makers (AMM) protocol, an algorithm that allows assets to be traded without permissions and sets the token price based on the ratio of assets in the pool rather than a traditional market of buyers and sellers. This technicality aligns with the crypto ideology of decentralization and individual control of assets (Makridis et al., 2023). Following the Bitcoin bubble in 2021, DEXs experienced significant growth in their share of trading volume compared to CEXs. In October 2023, the number of DEXs was 60% higher than that of CEXs. This growth can be attributed to the launch of Uniswap V3, one of the most successful DEXs, but also, since cryptocurrencies are distributed in users' wallets and not in the exchange's wallet, DEX appears more resilient against large-scale theft (Hägele, 2024; Makridis et al., 2023). The number of DEXs' users has been steadily growing, from 20 million users at the end of 2022 to over 64 million in June 2024[3].

The regulatory framework for crypto exchanges is currently limited, and a series of scandals, malfunctions and frauds, such as FTX, Celsius, The Rock Trading, and Voyager, have shown the weaknesses of the crypto economy's market infrastructures, posing risks to investors and the financial system. Some crypto exchanges represent a central and interconnected node in the crypto ecosystem, contrary to the DeFi philosophy. Even if CEXs are under state laws in the EU, which should provide investors with a sense of security, they could generate arbitrage opportunities. Also, in terms of risk, since DEXs, due to their decentralized structure, bypass KYC/AML regulations, they could create conditions for money laundering and illicit financial activities (Hägele, 2024). Moreover, due to the absence of disclosure obligations around interconnections and exposure, activities such as crypto stacking and crypto staking pose regulatory challenges and increase investors' inherent risks (Arner et al., 2024). To address these problems, regulators are introducing a new regulatory framework for crypto-assets exchanges (see more in detail Sect. 3).

[3] https://dune.com/rchen8/defi-users-over-time.

2.5 Players

2.5.1 Miners

Miners are integral to the crypto ecosystem, as their activities significantly impact the distribution of newly generated crypto-assets and maintain the blockchain's structure. They verify and package new transactions into blocks, with only the latest valid blocks universally confirmed and added to the blockchain. Miners are compensated for their verification efforts through transaction fees and newly minted cryptocurrency, often called block rewards. Over the last decade in the Bitcoin ecosystem, while the central role of miners has remained unchanged, their numbers have significantly decreased, from a peak of 67,911 in 2010 to just 144 in 2019. This decline highlights a shift in the reward system, which has become more concentrated among a few highly active miners due to advancements in mining technology, increasing mining costs, and the rise of large-scale mining operations. The overall hash rate has continued to rise, indicating that mining operations have become more efficient and concentrated among fewer participants. By 2019, Bitcoin mining distribution followed Zipf's law, where 80% of the mining reward was earned by 20% of miners, concentrating mining rewards and computational power among the top 10 miners. China was the largest crypto miner until late 2021 (after 2021, mining is banned in China), followed by US and Kazakhstan.

Regulatory events—such as China's crypto ban in 2021—and technological events like Bitcoin halvings have significantly impacted miners' activity, reducing either their operations or block rewards, and causing shifts in the cryptocurrency mining industry. Halving refers to the process of reducing the rate at which new bitcoins are created, cutting the block reward in half approximately every four years (or every 210,000 blocks). This built-in scarcity mechanism influences Bitcoin's supply-and-demand dynamics over time, potentially shaping its long-term price trajectory and affecting the broader cryptocurrency market. As of April 19, 2024, Bitcoin experienced its fourth halving, reducing the miner reward from 6.25 BTC to 3.125 BTC per block. This cyclical event plays a crucial role in maintaining Bitcoin's deflationary nature and continues to influence miners and the market. A summary of key technological events can be found in the Appendix.

2.5.2 Core developers

Core developers, or coders, play a crucial role in crypto-asset governance, directly intervening in the network protocol for periodic updates. There are three types of core developers: catalysts, who are project founders; open-source developers, who are unpaid volunteers; and freelance coders, whom companies pay. Initially, Satoshi Nakamoto created and managed the code, later involving other experts and programmers from the Cryptography Mailing List, which became the Bitcointalk Forum. After Nakamoto's departure in 2011, Gavin Andresen refused to manage the system alone, leading to the involvement of four other developers as Bitcoin Core developers, who maintain the GitHub Bitcoin Core repository. These developers must consider the general principles of the project, minimum requirements for inclusion, and participant consensus when making changes. Today, the Bitcoin network consists of an infrastructure governed by a reduced number of mining pools and developers across different jurisdictions, sharing the responsibility for managing and main-

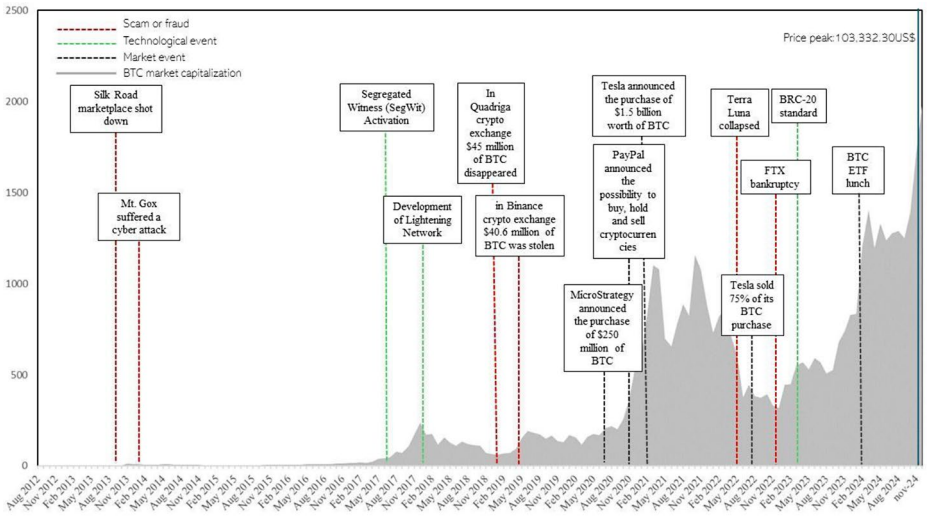
taining the network, contrasting with traditional centralized models where the responsible entity is always identifiable.

2.5.3 Users

User data for individual cryptocurrencies are unavailable. Bitcoin, for example, was designed to prevent tracking by banks and governments. However, as of November 2023, the crypto asset user base was estimated at 575 million, showing a nearly 190% increase between 2018 and 2020 (Statista). Investors owning crypto assets from 2019 to 2024 were primarily based in the United States and Russia, with significant growth observed in India, Africa, and Latin America in 2024.

Cryptocurrency investors, identified as early adopters and technology enthusiasts, exhibit a greater affinity for risk and unique investment patterns than traditional stock traders (Lindman et al., 2017; Kim et al., 2020). Motivations for investing in Bitcoin include ease of acquisition, the desire for profit, and support for Bitcoin's pro-social ideology (Fisch et al., 2022; Jin, 2024; Mattke et al., 2021). Unlike traditional investors, crypto-asset investors are driven by "technological motives" and exhibit herding behavior and anchoring biases, leading to market inefficiencies and speculative bubbles (Benedetti & Kostovetsky, 2021). These investors often sell their tokens on an exchange before the underlying product is developed, focusing on funding tech ventures and aligning with their interest in financing innovative technology start-ups.

The utilization and acceptance of Bitcoin are challenging to track and remain relatively limited. Since its introduction in 2010, numerous events have shaped the trajectory of Bitcoin's adoption, pricing, and market capitalization. Figure 1 illustrates the market capitalization of Bitcoin over time, highlighting 14 significant events, while the Appendix provides a detailed timeline of key developments that have influenced the cryptocurrency era. The events are categorized into three categories: market, regulation, and technology. Techno-



Own elaboration from CoinMarketCap

Fig. 1 Market capitalization of Bitcoin from August 2012 to 15th December 2024

logical innovations, such as the activation of Segregated Witness (SegWit) in 2017 and the implementation of the Lightning Network in 2018, were introduced to enhance transaction speed and scalability, and reduce transaction fees. Between 2020 and 2021, cryptocurrency adoption accelerated significantly, spurred by endorsements from major corporations such as Tesla, MicroStrategy, and PayPal. However, subsequent challenges—including rising inflation, fraudulent activities, data breaches, and the collapse of major exchanges—led to the onset of the so-called "crypto winter," a prolonged period of market downturn during 2022 and 2023, during which users and institutions liquidated their holdings. The recovery phase began in early 2024 with the launch of a Bitcoin Exchange-Traded Fund (ETF), representing a critical milestone in the broader adoption of cryptocurrencies. Finally, in December 2024, the price of Bitcoin reached new highs, topping $103,000 for the first time following the election of President Donald Trump and his plans to establish a U.S. Bitcoin strategic reserve.

2.5.4 Own elaboration from coinmarketcap

Decentralized Autonomous Organizations (DAOs).

DAOs are blockchain-based entities operating without centralized control, managed and governed collectively through smart contracts (Bellavitis et al., 2023; Santana & Albareda, 2022). Defined by decentralization, automation, and autonomy, DAOs use governance tokens to grant voting power to holders, with significant decision-making influence often concentrated among institutional investors or initial developers. One of the largest DAOs, Uniswap, had a capitalization of $3.4 billion in 2023. DAOs represent a new organizational form that potentially reduces transaction and agency costs while increasing transparency and innovation. However, challenges include security risks, as demonstrated by The DAO hack in 2016, and the persistence of traditional corporate governance issues, with new complexities arising from the involvement of miners-developers and founders-DAOs. Additionally, the requirement for voting on every decision can lead to coordination inefficiencies, increasing voting time and the number of inactive participants (Bellavitis et al., 2023).

3 Regulation

At the international level, the Financial Stability Board (FSB) is advancing a global regulatory framework grounded in the principle of "same activity, same risk, same regulation," aiming to ensure consistent and comprehensive regulation of crypto-asset activities and stablecoins relative to the risks they present, while also fostering responsible innovation prompted by technological advancements (FSB, 2023). The FSB's recommendations are twofold: (1) regulating, supervising, and overseeing crypto-asset activities and markets (CA recommendations), and (2) regulating, supervising, and overseeing global stablecoin arrangements (GSC recommendations). These guidelines reflect a growing interest among supervisory authorities in global stablecoins despite Bitcoin's prominence in value and usage among various cryptocurrencies.

In Fig. 2, we present a timeline of the main regulatory interventions worldwide. The European Union (EU) and the United States (US) are actively addressing regulatory challenges in the crypto space, employing distinct approaches to different categories of crypto-assets,

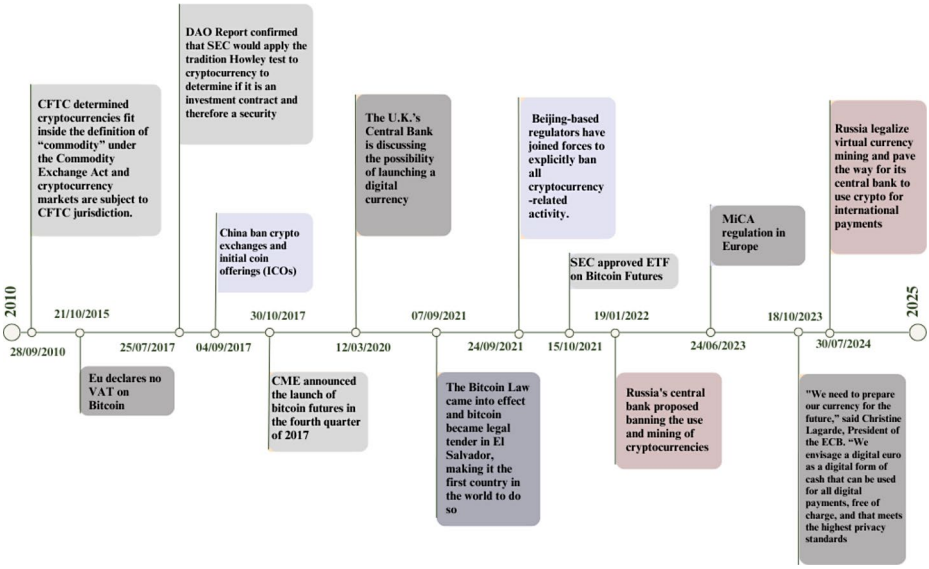


Fig. 2 Regulatory interventions timeline

as detailed in Sect. 2. Other countries, such as China and Russia, have adopted varying approaches to cryptocurrency regulation. China banned ICOs in 2017 and prohibited all cryptocurrency-related activities in 2021, significantly impacting mining activity across the entire market. In contrast, Russia has shifted its stance both before and after the conflict with Ukraine, recently legalizing cryptocurrencies as a means of payment. El Salvador was the only country to recognize Bitcoin as a legal currency and offer incentives for its adoption in 2021. The following section provides a brief overview of the regulatory landscape in the EU and the US. A comprehensive review of the approaches and policy measures of 19 jurisdictions can be found in FSB (2023).

3.1 The European union

The primary legislative framework in the European Union (EU) for cryptoassets is the Markets in Crypto-Assets regulation (MiCAR), which introduces uniform market rules for crypto-assets not currently regulated under existing financial services legislation, specifically stablecoins, utility tokens, and partially non-fungible tokens (NFTs). Security tokens, however, fall under Directive 2014/65/EU (MiFID II) and are treated as traditional securities offerings, necessitating IPOs rather than ICOs. The EU's regulatory approach to cryptocurrencies, particularly Bitcoin, remains indirect. As MiCAR primarily targets stablecoins and utility tokens, fully decentralized crypto assets, including Bitcoin, are excluded, as well as the fully decentralized issuance of tokens and the fully decentralized provision of crypto-assets services. In contrast, the provision of crypto-services about tokens (even when originally issued in a fully decentralized way) and the subsequent offering through/admission to a crypto-exchange are instead activities covered by MiCAR. Consequently, MiCAR does not encompass all recent developments in decentralized finance (DeFi) or new activi-

ties provided by Crypto-Asset Service Providers (CASP), such as crypto staking service (ESMA, 2024) or crypto lending.

Moreover, MiCAR categorizes stablecoins into two types: asset-referenced tokens and e-money tokens. Asset-referenced tokens are crypto-assets that maintain a stable value by referencing other values or rights, including official currencies, and their issuers are subject to authorization and stringent procedures for public offering and trading. Issuers of asset-referenced tokens face even more restrictive rules and are subject to supervision at the EU level[4]. E-money tokens, conversely, are linked to the value of a single official currency and are regulated similarly to electronic money under existing directives, with specific rules on issuance, redemption, and white paper requirements. Issuers of significant e-money tokens are subject to enhanced capital, interoperability, and liquidity requirements.

The regulation also addresses utility tokens, which fall under a residual category distinct from asset-referenced and e-money tokens. Utility tokens require public offering and trading conditions, including the publication of a white paper, though these requirements are less stringent than those for stablecoins. Furthermore, MiCAR introduces a framework for crypto-asset service providers, including those operating trading platforms for crypto-assets not classified as securities. These providers must ensure system resilience, transparency in trading processes, and adherence to non-discriminatory rules for platform access. They are also required to manage transaction settlements effectively, both on-chain and off-chain.

3.2 The United States

The regulatory landscape for Bitcoin and other crypto assets in the United States is characterized by fragmentation, with multiple federal agencies and diverse state regulations involved. The Securities and Exchange Commission (SEC) categorizes cryptocurrencies as securities, thus falling under its investor protection mandate. In 2024, the SEC approved eleven spot Bitcoin exchange-traded funds (ETFs). Conversely, the Commodity Futures Trading Commission (CFTC) classifies cryptocurrencies as commodities. Additionally, the Digital Commodity Consumer Protection Act (DCCPA) authorizes the CFTC to regulate "digital commodity platforms" and trading. The Internal Revenue Service (IRS), meanwhile, treats crypto assets as property for tax purposes[5].

Within this decentralized network of U.S. financial regulators, market participants exhibit varying responses to different regulatory bodies. Research indicates that crypto asset prices react more negatively to SEC actions than to CFTC enforcement, suggesting that crypto markets discern differences in enforcement paradigms between the agencies (Guseva & Hutton, 2023). Regarding stablecoins, the Toomey Stablecoin Bill has governed their issuance since 2022, distinguishing them from securities. On April 17, 2024, U.S. Senators Cyn-

[4] The criteria for determining whether stablecoins or e-money tokens are significant are both qualitative and quantitative. To be considered "significant", three of the following five criteria must be met: (i) Large user base: the size of the issuer or providers' customer base should exceed 10 million; (ii) High market capitalization: the total value of the tokens issued must exceed 1 billion euros; (iii) High transaction volume: the average value of daily transactions should exceed 500 million euros; (iv) Cross-border activity: the issuer's token offering is available in over seven EU member states; (v) Interconnectedness: the token has strong links with the traditional financial system or is used by a significant number of financial institutions.

[5] In SEC v Ripple Labs, Inc., Bradley Garlinghouse, and Christian A. Larsen (20-cv-10832, December 20, 2022), the SEC Charges Ripple and two executives with conducting $1.3 Billion Unregistered Securities Offering (available at https://www.sec.gov/newsroom/press-releases/2020-338).

thia Lummis and Kirsten Gillibrand proposed legislation to establish a specific regulatory framework for stablecoins. This draft legislation defines payment stablecoins and stipulates that they may only be issued by state non-depository trust companies registered with the Federal Reserve, with a nominal value cap of $10 billion, and excludes algorithmic stablecoins from issuance. For securities tokens, the Howey test[6] has been employed to determine whether a token offering should be accompanied by a prospectus. If the evaluation is negative, the issue can proceed using a white paper.

This regulatory patchwork reflects the ongoing development of federal laws concerning these assets. A new proposal, the Financial Innovation and Technology for the 21st Century Act (2024), seeks to clarify the regulatory roles of different public authorities. It specifies that the CFTC should regulate decentralized digital assets as commodities, while the SEC should oversee them as securities when the blockchain is functional but not decentralized. At the time of writing, this draft law is under Senate scrutiny. Initial commentaries suggest that it presents incomplete solutions ill-suited to the rapidity of such innovative markets. Critics argue that imposing traditional models of regulation and self-regulation risks overlooking the considerable economic potential of these new technologies while failing to precisely target the risks, transaction costs, and negative externalities associated with digital asset trading. To address these challenges and the gaps in the institutional self-regulation of blockchains, Guseva (2024) advocates for a two-tiered self-regulation organization (SRO) structure, comprising a policy-level SRO and crypto exchange-SROs. This proposed structure aims to provide comprehensive market oversight, discipline bad actors, reduce transaction costs, and enhance market integrity.

4 Evaluating crypto ideology

After sixteen years of technological developments, crypto ideology presents many of the classic trade-offs and externalities that characterize the traditional financial system. In what follows we first critically discuss the main promises (disintermediation, financial inclusion and greater efficiency) heralded by crypto-supporters and then tackle major tradeoffs arisen in the development of the crypto ecosystem.

4.1 Dis- or re-intermediation?

The foundational principle of DLT and cryptocurrency ideology is disintermediation, which seeks to eliminate the control traditionally exercised by banks, institutions, and authorities. Proponents assert that Bitcoin's blockchain, with its distinctive features, promises a higher level of trust in transactions by removing intermediaries and disrupting conventional financial governance (De Filippi & Loveluck, 2016). However, this notion of complete disintermediation is challenged by critics who argue that blockchain management, despite relying on automated mechanisms, still necessitates human intervention for maintaining protocols and improving systems (Nabilou, 2020). Research indicates that, while nodes, miners, and developers engage in network management, human influence remains significant (De Filippi & Loveluck, 2016). The increasing computational difficulty associated with Bitcoin mining has resulted in the consolidation of hashing power within a few large mining pools,

[6] SEC v. W.J. Howey Co., 328 U.S. 293 (1946).

leading to a quasi-centralized network with oligopolistic characteristics. This concentration of power becomes particularly apparent during conflict resolution, where control over computational resources can determine the outcome of network forks. Consequently, despite technological advances promising disintermediation, human involvement and oligarchic tendencies persist within the Bitcoin network, challenging the idea of a truly decentralized system. This issue is also animating an intense academic debate within the legal literature, as the DeFi poses direct and major challenges for traditional, geographically based, nation-state legal systems (Zetzsche et al., 2020). DeFI indeed seeks to eliminate the role of the state as a rule-maker and enforcer while any existing laws - in particular, civil law and business organizations law- were meant and conceived for hierarchical and centralized organizations governed by strict governance rules and appear difficult if not impossible to apply in the context of network-based and automated ecosystems (Macchiavello, 2022). Specifically, challenges arise in establishing the legal standing to file a lawsuit, identifying the applicable law and the jurisdiction of regulatory bodies, supervisory authorities, and courts, weakening the enforcement of the rule of law in financial services. Therefore, scholars in the legal and regulatory discussions tend to support the idea of exploring alternative regulatory approaches specifically designed to address the complexities of DeFi, rather than relying solely on traditional financial regulations (Macchiavello, 2022; Walch, 2019; Zetzsche et al., 2020).

4.2 Financial inclusion or exclusion?

A common theory in crypto ideology suggests that decentralization will improve financial inclusion, particularly for unbanked populations in regions like Latin America, Africa, and Asia, by providing a cost-effective means to access financial services. Advocates often emphasize cryptocurrencies' potential for affordable cross-border money transfers and financial services accessible via smartphones. Additionally, there is an expectation that cryptocurrencies will act as investment vehicles promoting upward economic mobility. However, the anticipated benefits of financial inclusion remain largely unrealized due to several obstacles. First, the digital divide in emerging economies hampers stable internet access and the use of information and communication technologies. Second, many cryptocurrency exchanges require bank accounts, excluding unbanked and low-income individuals. Transaction fees, including network and exchange fees, often surpass those of traditional money transfer services, further limiting access. Despite growing adoption, cryptocurrencies remain a niche sector, revealing a significant gap between their potential benefits and the needs of underserved populations. Regarding wealth generation, investing in cryptocurrencies demands a high level of technological and financial literacy (Meoli et al., 2022). Many investors lack the necessary knowledge and often follow market trends rather than making informed decisions, leading to substantial financial losses. The failures of prominent crypto entities like TerraUSD and FTX in 2022 underscored these risks, as smaller investors faced significant challenges and losses (BIS, 2023).

These arguments also extend to entrepreneurial finance. ICOs, Initial Exchange Offerings (IEOs), and Initial DEX Offerings (IDOs) are proposed as alternatives to traditional fundraising methods like crowdfunding and IPOs, potentially democratizing access to capital in a digital age (Cumming et al., 2021; Fisch et al., 2022). Nevertheless, the crypto market has seen a rising presence of institutional investors, such as crypto funds, indicating a grow-

ing degree of intermediation. Evidence from various studies highlights that crypto funds, including family offices and hedge funds with fewer regulatory constraints, are increasingly influential in decentralized finance (DeFi) (Bianchi & Babiak, 2022; Dombrowski et al., 2023; Fisch & Momtaz, 2020). By late 2023, over 868 crypto funds worldwide managed assets amounting to approximately US$70.11 billion, demonstrating enhanced efficiency in the ICO market by reducing search frictions and improving funding outcomes (Crypto-Funds Report, 2023). The rise in intermediation can be attributed to high participation costs and specific risks within the crypto market, such as the need for extensive market research and due diligence to address information asymmetry and potential technological breaches (Cumming et al., 2025; Momtaz, 2024). As a result, rather than decreasing intermediation, the crypto ecosystem is evolving to incorporate and necessitate it.

4.3 Efficiency or inefficiency?

Crypto ecosystems and DeFi platforms leverage blockchain and smart contracts to reduce transaction costs and time. However, their effectiveness in enhancing search efficiency and mitigating resource misallocations remains underexplored (Momtaz, 2024). DeFi markets, characterized by high granularity and completeness, enable anyone to trade tokenized assets with minimal cost, but this granularity also increases the effort required to screen deeper markets. This issue is particularly acute in the ICO market, where DLT and smart contracts, while promoting market participation and segmentation, lack technological solutions to ease search frictions. As discussed above, inefficiencies might undermine the viability of fully decentralized fundraising, suggesting that entrepreneurial finance may gravitate back toward intermediated models. Investigating how decentralized systems integrate AI-driven tools to screen early-stage ventures, where data scarcity and the need for rapid, accurate selection are critical, is particularly relevant. Comparative studies could investigate whether DeFi can outperform traditional finance in fostering innovation while mitigating these inefficiencies.

4.4 Stabilizing or destabilizing?

The theoretical benefit of a diversified financial system is increased resilience and stability through the advantages of biodiversity, suggesting that the coexistence of traditional finance (TradFi) and the crypto ecosystem should ideally enhance overall financial stability. However, recent events have demonstrated that the crypto and DeFi ecosystems share vulnerabilities with traditional financial systems, potentially diminishing the stabilizing effect of diversification. The “crypto winter” of 2022, marked by the collapse of Terra/Luna and FTX, revealed the inherent risks in crypto assets and DeFi markets, with significant value losses (FSB, 2023; FSI, 2023). Initial analyses suggested limited contagion risk between the crypto and TradFi sectors due to minimal interconnectedness. However, in 2023, several bank failures- banks linked to crypto and startup ventures, including Silicon Valley Bank, Signature Bank, and Silvergate Capital—highlighted potential risks. Although regulatory interventions mitigated immediate impacts, these failures stress the need for a robust regulatory framework to address risks in the DeFi ecosystem. The vulnerabilities inherent in DeFi, such as operational fragilities and reliance on smart contracts, combined with the volatility of crypto assets, amplify these risks. Additionally, the novelty and lack of transparency in

the underlying technology, along with non-compliance with existing regulations, exacerbate the potential for destabilizing outcomes.

4.5 Blockchain for good or bad?

Blockchain technology exhibits a dual nature, facilitating both legitimate and illicit economic activities. Cryptocurrencies possess several features that make them particularly attractive to scammers, which may help explain why reported losses in 2021 were nearly sixty times higher than those in 2018. The absence of a central authority, such as a bank, to flag suspicious transactions and intervene to prevent fraud is a significant vulnerability. Additionally, cryptocurrency transfers are irreversible—once funds are transferred, they cannot be recovered. Compounding this issue, many individuals remain unfamiliar with the mechanics of cryptocurrencies. While these challenges are not unique to cryptocurrency transactions, they collectively create an environment that is highly advantageous for scammers. Consistently, the U.S. Federal Trade Commission reports that a substantial proportion of cybercrime involves blockchain technology and cryptocurrencies[7]. Although the existing literature has begun to explore the role of blockchain in cybercrime (Hornuf et al., 2023), significant gaps remain in understanding the intricate dynamics between technological innovation and criminal exploitation.

4.6 Environmentally sustainable or unsustainable?

Environmental issues are increasingly integral to crypto ecosystems. Fintech's digital services offer several inherent advantages in advancing sustainability objectives. The transition to digital platforms naturally protects the environment by reducing reliance on energy-intensive physical services and infrastructures (Billio et al., 2024). While existing research has documented fintech's potential benefits for environmental protection, social equity, and governance improvement through digital services and stakeholder-centric platforms (Cumming et al., 2024), critical questions remain about the true environmental cost of these technological advances. Of particular importance is examining how the significant energy consumption of data centers and digital infrastructure affects the net environmental impact of fintech solutions. Future studies should investigate optimal design frameworks for environmentally sustainable fintech platforms that maximize ESG benefits while minimizing ecological footprints.

5 Conclusions

This paper provided a comprehensive overview of the crypto ecosystem, tracing its evolution from the inception of Bitcoin to the current landscape dominated by a diverse array of cryptocurrencies, tokens, and DeFi applications. It examined the technological foundations, such as blockchain and DLT, and the various financial instruments and participants that define the crypto market. The paper also explored regulatory frameworks and the ideologi-

[7] https://www.ftc.gov/news-events/data-visualizations/data-spotlight/2022/06/reports-show-scammers-cashing-crypto-craze.

cal promises of decentralization, financial inclusion, and systemic stability, assessing the extent to which these promises have been fulfilled.

This study contributes to the literature by synthesizing existing research on the diverse aspects of the cryptocurrency ecosystem, emphasizing the interplay between technological innovation and financial market dynamics. It highlights the critical role of regulatory developments and the challenges arising from the rapid expansion and inherent risks associated with cryptocurrencies and DeFi. By integrating insights from technological, financial, and regulatory perspectives, this paper offers a deeper understanding of crypto-assets. It examines their potential benefits and limitations, as well as their influence on traditional financial systems. Additionally, the study provides a comprehensive overview of the evolving challenges within DeFi and underscores the need for an interdisciplinary analytical framework to effectively address its complexity.

Future research should focus on several key areas to further advance the field. First, there is a need for more empirical studies on the real-world applications and socio-economic impacts of cryptocurrencies, particularly in emerging markets. Second, investigating the long-term implications of regulatory frameworks and their effectiveness in mitigating risks without stifling innovation is crucial. Finally, exploring the intersection of technological advancements, such as artificial intelligence and blockchain, could provide valuable insights into the future trajectory of DeFi and its integration with traditional financial infrastructures.

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