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RESEARCH ARTICLE

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Finance infrastructure through blockchain-based tokenization

Abstract The infrastructure finance gap has long-standing implications for economic and social development. Owing to low efficiency, high transaction costs, and long transaction time, conventional infrastructure financing instruments are considered to be major contributors to the increasing mismatch between the need for infrastructure development and available financing. Implemented through smart contracts, blockchain tokenization has shown characteristics that are poised to change the capital stack of infrastructure investment. This study analyzed the first SEC-compliant energy asset security token, Ziyen-Coin, from the perspective of the key participants, relevant regulations, and token offering procedures. Results show that tokenization can improve infrastructure assets liquidity, transaction efficiency, and transparency across intermediaries. Conventional infrastructure financing instruments were compared with blockchain tokenization by reviewing the literature on infrastructure finance. The benefits and barriers of tokenizing infrastructure assets were thoroughly discussed to devise ways of improving infrastructure financing. The study also found that the potential of tokenization has not yet been fully realized because of the limited technical infrastructures, regulation uncertainties, volatilities in the token market, and absence of the public sector. This study contributes to the present understanding of how blockchain technology can be implemented in infrastructure finance and the role of tokenization in the structure of public–private partnership and project finance.

Keywords infrastructure asset, blockchain, tokenization, security token offering, smart contract, public–private partnership, project finance

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1 Introduction

As fundamental aspects of facilities and systems, infrastructures, such as roads, railways, ports, airports, power, and communication, play a vital role in social development. Infrastructure connects people, businesses, and communities to support economic growth and improve quality of life. A study by the European Bank for Reconstruction and Development (EBRD, 2017) revealed that every dollar invested in infrastructure has a 60-cent return on investment in the short- and long-term productivity of an economy. Although the state of a nation's infrastructure system plays an important role in its economic prosperity, social welfare, and national security, the mismatch between the need for more and better infrastructure and the available financing continues to increase. According to the American Society of Civil Engineers (ASCE, 2017), a $3.6 trillion funding gap needs to be filled to upgrade the crumbling infrastructure system of the USA. Meanwhile, McKinsey reported a 1% GDP spending shortfall between 2007 and 2012 due to infrastructure underspending in less developed economies (Walter, 2016).

As an asset class, infrastructure is characterized by high capital intensity, long return on investment duration, illiquidity, complexity, and significant social spillover effects (Walter, 2016). Infrastructure is divided into three categories: (i) social (e.g., roads, schools, and hospitals), (ii) regulated (e.g., mass transit, electric and water utilities, and stormwater treatments), and (iii) demand-driven (e.g., telecommunications, ports, airports, renewable energy, and green buildings) infrastructure. Social infrastructure is typically financed by public means, including municipal bonds ($5.6 trillion outstanding in the USA alone) that are supplemented by debt financing from infrastructure banks or state revolving funds at concessionary interest rates. Regulated and demand-driven infrastructure often engages in private financing through public–private partnerships (PPP) or private financing. The continuously increasing fiscal deficit, budgetary pressure, inefficiency of public financing, and politic uncertainty have aggravated the shortage in infrastructure investments.

In the 1990s, the public sector began experimenting with new forms of private sector involvement in public infrastructure to alleviate the fiscal policy constraints and leverage the inherent efficiencies in the private sector. For example, contractual models for PPP in transportation were introduced between the owners of most transportation infrastructure and a private entity (Cui et al., 2019). In a PPP project, a private sector consortium forms a special-purpose vehicle (SPV) to develop, build, maintain, and operate its assets for the contracted period, whereas the government typically allots an equity share. This consortium usually involves a building contractor, a maintenance company, and a syndicate of debt and equity investors. The SPV signs the contract with the government and subcontractors to build and maintain the facility. The remuneration structure between the government and the facility often includes fixed availability fees (performance-based payments), user fees (granting rights to a private company to offer services for a fee), or user-driven payments (public payments based on use) (Mason, 2017; Ramsey and El Asmar, 2020). Complex arrangements and contracts that guarantee and secure cash flows turn PPP projects into prime candidates for project financing. The federal government is usually not party to a PPP agreement. However, the structuring of PPP projects tends to be accessible only to experienced investors and sponsors (Lu, 2018).

Given its asset class characteristics, the current financing models for infrastructure limit the investments to a narrow set of institutional investors, thereby leaving a significant amount of capital on the sidelines. Owing to opacity, high transaction costs, illiquidity, and low secondary market activities, conventional infrastructure financing instruments fail to achieve a seamless collaboration between investors and financing issuers (Kim, 2016). Alternative financing instruments and operational models for infrastructure that can efficiently utilize diverse capital resources should then be used to align the interests of investors with those of project developers and asset owners and to subsequently address the public deficit (Della Croce and Yermo, 2013).

Efficient financing is achieved by coupling information on infrastructure performance, structural health, and other data streams to dividends, interest rates, or expected internal rates of return from capital asset appreciation (Blanc-Brude, 2013). Financial instruments, such as insurance or swap models, data securitization, and digital financing, involve an algorithmic implementation of financial transactions and valuation models that help address investment and project risk management (Brammertz and Mendelowitz, 2018). Digital finance may refer to the tokenization process, digital rights to ownership, or access to the value of an asset (Smith et al., 2019). Shifting to financial technologies has become possible with the introduction of computational technologies that leverage data streams from infrastructure digitization, such as blockchains (Constantinides et al., 2018).

Conceptualized by Nakamoto (2008), blockchain is a decentralized and trustworthy ledger system that stores immutable data chronologically in a chain of blocks. Tokenization represents one of the most successful implementations of blockchain technology that transforms its benefits into practice. Given the gradual transitioning of infrastructures to intelligent systems, blockchain-based tokenization may allow the application of alternative financing models for infrastructure projects (Curry et al., 2006; Kyriakides and Polycarpou, 2014). Tokenization also has the potential to unlock the liquidity of infrastructure assets, enhance transparency, and reduce transaction time and cost (Uzsoki, 2019; Tian et al., 2020). Although blockchain is considered an emerging technology, a plethora of working prototypes and collaborative initiatives targeting the transportation, energy, and agriculture industries are being developed to explore the various aspects of infrastructure investing.

To bridge the infrastructure financing gap through blockchain-based assets tokenization, the suitable types of infrastructure assets for tokenizing, the tokenization procedures, potential benefits of asset tokenization, the barriers to the wide uptake of tokenization at the current stage, and the role of tokenization in the structure of PPP and project finance are introduced and analyzed in this research.

2 Infrastructure

2.1 Infrastructure finance

Infrastructure projects are unique and heterogeneous in nature. Given its attributes (e.g., complexity, longevity, and large scale), infrastructure has been categorized as a special asset class that requires dedicated financial resources. A study by RARE Investment Infrastructure revealed that global infrastructure assets are approximately valued at $20 trillion (Walter, 2016). Figure 1 breaks down the ownership of infrastructure assets.

Infrastructure facilities are usually financed through fixed income products comprising municipal and private (corporate) bonds as well as senior and junior (mezzanine)

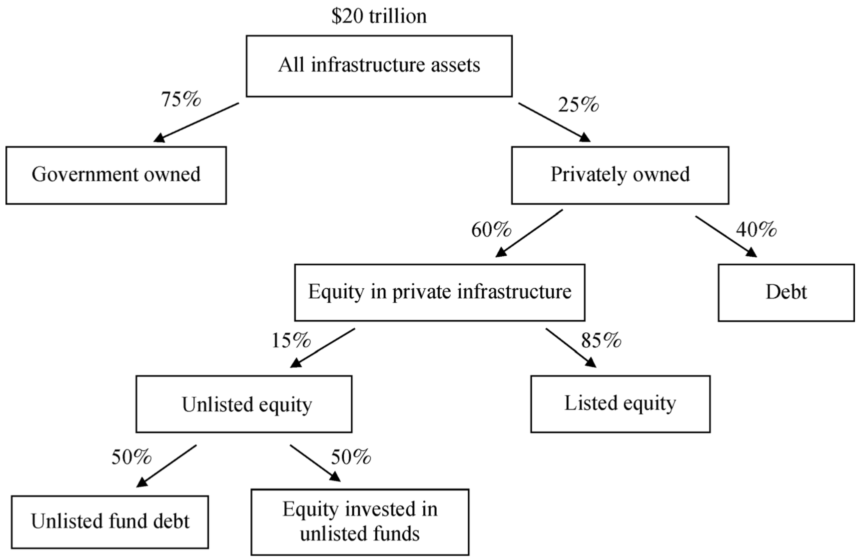

Fig. 1 Hierarchical distribution of infrastructure asset ownership (based on Walter (2016)).

debt. The infrastructures financed through traditional debt and equity (based on balance sheets of sponsors or government agencies) significantly differ from those financed through project financing (based on projected cash flows of the facility being financed). The combination of loans and bonds accounts for the most substantial portion of infrastructure finance. In the equity market, listed infrastructure equity funds, exchange-traded funds, trusts, indices, and unlisted (private) infrastructure funds are the most common sources of infrastructure finance. Table 1 presents a taxonomy of infrastructure financing instruments and vehicles.

2.2 Challenges in conventional infrastructure project finance

2.2.1 Limited liquidity

Infrastructure is a long-lived immobile asset. While similar to pension funds involving long-term fiduciary responsibilities, infrastructure investments are considered illiquid because of their limited trading options in secondary markets or the constraints in PPP contract agreements (Sandor, 2019). For instance, infrastructure bonds are issued through traditional private placements and are allocated by institutional investors, such as insurance companies, pension funds, or sovereign wealth funds. When these bonds are issued, they are held as permanent investment assets unless they are downgraded below the investable grade. This common practice, combined with limited secondary market trading, affects the liquidity of infrastructure assets and reduces the chance for refinancing (Walter, 2016).

Private sector investment in infrastructure requires a sophisticated analysis of deep domain knowledge in operational models and an understanding of risk exposures and management. The lack of necessary expertise and appropriate instruments with the desired risk and return characteristics and the perspective of the public toward engaging private financers in critical infrastructure have hindered private entities from investing in mainly demand-driven and regulated infrastructure. According to RARE Investment Infrastructure, 25% of all infrastructure projects around the world are privately owned (Walter, 2016). Meanwhile, pension funds and insurance companies worldwide only invest 0.8% of their $50 trillion of assets under management (AUM) in infrastructure assets (The Economist, 2014). Only the largest institutions have the necessary resources and domain knowledge to directly invest in infrastructure, whereas smaller investors can only resort to limited pooled investment vehicles, such as listed YieldCos or real estate investment trusts (REITs) in Table 1 (Kim, 2016).

2.2.2 Transaction inefficiency

The majority of the financing instruments available in the market have been criticized for low efficiency due to high transaction fees and misalignment with the performance attributes of infrastructure assets (Croce et al., 2015). Infrastructure investment funds often have high friction (transaction) costs associated with highly bespoke direct investments, fund management costs (e.g., carried interest), and other fees or expenses for operations and management.

A large number of intermediaries (e.g., banks, rating agencies, insurance providers, and interest swap providers) may also explain the decrease in transaction efficiency when using traditional financing tools (Clark, 2017) because settling a single transaction with the involvement

Table 1 Taxonomy of infrastructure financing instruments and vehicles (Croce et al., 2015)

Modes		Infrastructure finance instruments		Market vehicles
Asset category	Instrument	Infrastructure project	Corporate balance sheet /Other entities	Capital pool
Fixed income	Bonds	Project bonds, Municipal sub-sovereign bonds, Green bonds, Sukuk	Corporate bonds, Green bonds, Subordinated bonds	Bond indices, Bond funds, Exchange traded funds (ETFs)
	Loans	Direct/Co-investment lending to infrastructure project, Syndicated project loans	Direct/Co-investment lending to infrastructure corporate, Syndicated loans, Securitized loans, Collateralized loan obligations	Debt funds, Loan indices, Loan funds
Mixed	Hybrid	Subordinated loans/bonds, Mezzanine finance	Subordinated bonds, Convertible bonds, Preferred stock	Mezzanine debt funds, Hybrid debt funds
Equity	Listed	YieldCos	Listed infrastructure & utilities stocks, Closed-end funds, Real estate investment trusts, Infrastructure investment trusts, Master limited partnerships	Listed infrastructure equity funds, Indices, Trusts, ETFs
	Unlisted	Direct/Co-investment in infrastructure project equity, PPP	Direct/Co-investment in infrastructure corporate equity	Unlisted infrastructure funds

of multiple intermediaries usually takes a few days. Moreover, a unique and heterogeneous infrastructure development requires a comprehensive and complicated legal arrangement to ensure efficient operation. Legal arrangements are also important in clarifying the responsibilities of each party, ensuring proper payoff distributions, and establishing an appropriate risk-sharing mechanism. However, legal arrangements entail many intermediaries. Transactions of listed infrastructure asset securities can take as long as three days ($T + 3$) to complete (Uzsoki, 2019).

2.2.3 Lack of transparency

Information asymmetry always exists in infrastructure investment, starting from the procurement process up to the operation and maintenance phases (Ohashi, 2009; Estache and Iimi, 2010). The information needed by investors to understand a project is opaque and highly scattered. Moreover, the complicated and highly bespoke nature of infrastructure investments requires a substantial amount of time and resources for investors to understand and manage the associated risks. Conventional infrastructure financing instruments have failed to address these problems. Information asymmetry also involves risks related to widespread corruption, inadequate governance, and unfair competition, all of which can further dampen the interest of investors in infrastructure assets (Burguet and Che, 2004).

3 Blockchain and tokenization

3.1 Blockchain

Blockchain originates from the first cryptocurrency Bitcoin (Nakamoto, 2008). Blockchain is an open, distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way (Iansiti and Lakhani, 2017) that stores immutable data chronologically without the involvement of central authorities (Eyal et al., 2016). With the recent advancements in blockchain, a decentralized, immutable, and trusted system could be built (Crosby et al., 2016). Since the introduction of blockchain, both public and private sectors have explored opportunities to leverage such technology for their practical use (Swan, 2015). A report from the World Economic Forum revealed that 10% of the global GDP, or approximately \$12 trillion, will be passed through blockchain by 2025 (Herweijer et al., 2018). Blockchains are not limited to cryptocurrencies but can also be widely used in healthcare, real estate, supply chains, and finance, all of which can take full advantage of the information, data, and value storage of such technology (Underwood, 2016). Tokenizing valuable assets can be realized by implementing blockchain technology (Chen, 2018), which has application use cases in financing real estate (Smith et al., 2019), renewable energy and green buildings (Uzsoki, 2019), energy microgrid transactions (Mengelkamp et al., 2018), and intelligent transportation infrastructure (Gong and Liao, 2019; Khan et al., 2019; Zhong and Adriaens, 2020).

Most of the blockchain applications designed with smart contracts are permissionless, thereby allowing anyone to participate in the system. This type of application for infrastructure makes sense for investments in companies that own and operate assets, such as listed REITs and YieldCos, or initial coin offering (ICO)-funded companies. For direct investments in infrastructure-related applications, the blockchain can also be permissioned; that is, the transaction information should be validated by a selected group of investors or token holders and approved by the blockchain owner. This case is observed in many supply chain management applications in logistics and manufacturing industries. Permissioned systems tend to be more scalable and faster yet are more centralized than non-permissioned ones.

3.2 Tokenization

Tokenization is one of the applications of blockchain technology (Rohr and Wright, 2017) that allows users to digitize tangible and intangible assets, where each blockchain token represents a certain share of the asset ownership (Uzsoki, 2019). Information, value, and associated rights of an asset can be transferred onto the blockchain through tokenization (BANKEX, 2018). Similar to conventional securities, tokens representing an asset are tradable on secondary markets. Deloitte reported that "Tokenization could make the financial industry more accessible, cheaper, faster and easier, thereby possibly unlocking trillions of euros in currently illiquid assets, and vastly increasing the volumes of trades" (Laurent et al., 2018). An asset class, such as modern REITs, USA Internet stocks, or high-yield bonds, usually takes decades to rise above 1% of the global GDP after its emergence. However, the blockchain tokens market hit 0.8% of the global GDP in only two years. Asset tokenization may witness an unprecedented growth rate over the next decade (Burniske and White, 2017).

Blockchain tokens can be categorized into utility and security tokens (The Tokenist, 2019). Utility tokens are issued through ICOs (Chohan, 2019), a process in which issuers sell tokens in exchange for cryptocurrencies, such as Ethereum, without the governance of existing securities regulations (Adhami et al., 2018). Utility tokens grant their owners access to products or services that are offered by the issuing company (Conley, 2017). These tokens usually have tangible benefits. By contrast, security tokens are generated through security token offerings (STOs) (Pauw, 2019). Although the mechanisms that underlie ICO and STO are similar, the latter must comply with securities rules and have to be backed by financial assets, such as equities or fixed income. In 2018, STOs reached $509 million, representing a 2000% increase over the previous year (Dakshinamoorthy, 2019). Security tokens facilitate and accelerate transactions under the protection of existing security regulations. The USA Commodity Futures Trading Commission, Internal Revenue Service, and USA Securities and Exchange Commission (SEC) have provided some guidance on the tokenization of assets. This research only focuses on tokenization that complies with the existing security laws and regulations. Therefore, the term "tokenization" throughout the rest of this paper refers to regulated security tokenization.

Unlike utility and security tokens, stablecoins are cryptocurrencies designed to minimize volatility as they are pegged to a stable asset or a basket of assets, such as fiat currencies (e.g., USD), or exchange-traded commodities (e.g., precious or industrial metals) (Bullmann et al., 2019; Stein Smith, 2020). Organizations have started to issue stablecoins for the broader market, including the Gemini dollar and the Paxos standard token, both of which are regulated by the New York Department of Financial Services (considered one of the strictest regulators of cryptocurrencies). These stablecoins are backed by USD on a 1:1 basis and are subject to periodic audits to help ensure their validity. Owners of either of these stablecoins can trade in their coins for dollars at any time and send these dollars to any address. As the valuations and value associated with these coins become more apparent and easily verifiable, both attestation professionals and organizations dependent on data verification can comfortably use these coins as actual assets (Tomkies and Valentine, 2019). Stablecoins represent a fundamental shift in how the cryptocurrency market is classified, reported, and evaluated by financial service professionals, thereby enhancing their potential application in certain use cases in infrastructure investments.

3.3 Smart contract

Blockchain tokens are governed and executed through smart contracts, which are self-executing and self-enforcing contracts with agreements approved by all parties and written into code (BANKEX, 2018). Blockchain is a technology through and on which smart contracts are built and based (Clack et al., 2016; Delmolino et al., 2016). Credible transactions through smart contracts are traceable and can be verified without the involvement of external third parties or a centralized authority (Buterin, 2013; Norta et al., 2018). As a result, the terms and conditions specified in smart contracts are accessible and visible, thereby bringing transparency, accuracy, and trust to involved parties. An automated contract execution enables speedy, secure, and efficient transactions (Bogner et al., 2016). In asset tokenization, those tokens with target values or performance criteria defined in the contract terms can be transferred to investors without human intervention and recorded in the blockchain when the contract terms are met.

3.4 ERC-20

ERC-20 defines a list of standards that Ethereum tokens follow (Vogelsteller and Buterin, 2015). ERC-20 ensures a cross-compatibility among different Ethereum-based Dapps tokens, thereby allowing these tokens to be traded, exchanged, or transferred to crypto wallets and facilitating the integration of various projects into the ecosystem. ERC-20 tokens are the most popular tokens used in smart contracts designed for the permissionless Ethereum blockchain platform. The share of ERC-20 tokens in the overall token market (AminCad, 2018) accounts for the most of the tokenization projects available in the market (Reiff, 2019).

4 Infrastructure tokenization

4.1 Types of infrastructures suitable for tokenization

Tokenization is generally considered suitable for those investable infrastructure assets that can generate long-term stable cash flows, remain well-structured throughout the entire project lifecycle, and play important roles in supporting economies. Specifically, investable infrastructure must embody seven core characteristics, namely, public use, monopolistic power, government related, essential, cash generating, conductive to the privatization of control, and capital intensive with long-term operational horizons (Anson et al., 2012). The suitability of an infrastructure asset for tokenization is measured by the extent to which these seven elements are met. Infrastructure asset appreciation and long-term stable cash flows are incentives that attract investors to participate in the tokenization of infrastructure assets.

4.2 Tokenization process

The first step in issuing blockchain tokens for infrastructure is to identify the underlying infrastructure asset that must be evaluated and audited in compliance with the existing laws and security regulations. The risk and return expectations of an investment in a facility, along with its potential for revenue streams and cash flow uncertainties, must also be well understood. Tokenization is suitable for project finance or for PPPs with concession agreements between the public asset owner and the private sector operator. SPV is formed after the initial identification process in order for the tokenization to take place (Della Croce and Gatti, 2014). In the case of the USA, Regulation D and S filings are required to issue security tokens to accredited USA (Ziyen, 2019) and non-USA investors, respectively. The decision on whether a permissioned or permissionless blockchain transaction system will be required for an asset should also be made based on the level of trust among the investor participants and the ability to scale investment. After the legal and deal structures for asset tokenization are established, the provider of security token issuance services, the know your customer/anti-money laundering (KYC/AML) vendor, custody service provider, and primary/secondary marketplaces are determined and confirmed (Lootsma, 2017). Smart contracts are generated to address the necessary requirements and regulations. The management of SPV sets prices for security tokens. Potential investors need to pass KYC/AML checks to invest in security tokens. After completing these processes, newly minted security tokens can be transferred to the wallets of accredited investors or be listed on token exchanges. "Wallets" refer to digital storage facilities in which blockchain tokens are deposited. Accredited investors can transfer their tokens to other accredited investors or trade these tokens on secondary markets. The future dividends and interest payouts generated from tokenized assets are sent out to the wallets of token owners in the form of cryptocurrencies or equivalent fiat currency. Figure 2 illustrates the infrastructure tokenization process.

4.3 Key participants in infrastructure tokenization

Apart from token issuer and investor, tokenization of infrastructure also involves several other major participants, such as the issuance services provider, escrow company, regulator, legal firm, and secondary trading

Origination	Digitization	Distribution	Exchange	Post-Tokenization Management
Due diligence Design deal structure Determine the terms and conditions of the digital token backed by infrastructure assets Code legal and regulatory requirements into smart contracts File documents	Appraise infrastructure assets Establish SPV Select technology platform Program smart contracts Transfer transactional information onto the blockchain	Evaluate investors KYC/AML Price tokens Distribute tokens to primary investors in exchange for investment capital Store transactional information automatically onto the blockchain without the participation of intermediaries	Manage whitelist Trade on secondary markets (token exchange or traditional capital markets) Peer-to-peer transfer	Distribute dividend Enable shareholder voting Reporting Taxing Accounting

Fig. 2 Infrastructure asset tokenization process.

platform. The primary role and responsibilities of each participant are described as follows:

Issuer: Develops the infrastructure facility and designs deal structures.

Investor: Accredited investors interested in infrastructure assets.

Issuance services provider: Offers the essential expertise and technology infrastructure, designs smart contracts, and assists asset owners in launching tokens.

Escrow services provider: Provides KYC/AML services, maintains a whitelist of accredited investors and verifies token transfers.

Legal firm: Designs legitimate deal structures to ensure compliance with regulations.

Regulator: Government agencies that are responsible for the financial regulation of securities. Such as the SEC and the Financial Services Authority act as regulators in the USA and UK, respectively.

Trading platform: Registered security token exchanges that are regulated by security rules.

4.4 Advantages of infrastructure tokenization

Tokenization can create a transparent and democratized system by significantly reducing friction during token creation, distribution, and transaction. The main advantages of tokenization include enhanced liquidity, increased transaction efficiency, and improved transparency. Table 2 compares the conventional infrastructure financing instruments with infrastructure asset tokenization.

4.4.1 Enhanced liquidity

Tokenization expands the infrastructure asset class from the domestic market to global markets. The bulk amount of up-front investment can be divided into fractional investment units to enable the participation of retail and small institutional investors in tokenization. This concept has a track record in real estate investing with companies such as RealIT and SolidBlock, where fractional ownership allows ordinary investors to overcome a significant entry barrier. Tokenization allows the conversion of real estate from somewhat illiquid assets into liquid assets. This process can also create secondary trading opportunities for investors. Tokens are expected to be traded in real-time on global markets, thereby narrowing bid-ask spreads, increasing market depth, and generating additional liquidity for infrastructure assets. Given the low risk, non-speculative nature of social infrastructure assets, tokenization using stablecoins may be preferred over the more volatile security or utility tokens.

4.4.2 Increased transaction efficiency

By incorporating smart contracts, transactions, dividends, and interest distribution, the storage and administration of information are executed automatically in a blockchain based on triggers coded in a contract. Value proposition requires minimal involvement from legal, financial, regulatory, and other intermediaries, thereby reducing the associated transaction costs. Given that token transactions are completed on a peer-to-peer basis through the Ethereum blockchain, it shortens transaction time. Ethereum-based token transactions are confirmed within a few seconds (median waiting time of 36 s).

4.4.3 Improved transparency

Blockchain is a distributed database owned democratically by nodes all over the world in a permissionless system or

Table 2 Comparison between conventional financing instruments and infrastructure asset tokenization

Host's view/features	Direct government spending	Government, municipal, and sub-sovereign bonds	Commercial loan (senior or subordinated)	Listed equity funds	Unlisted direct equity investment and co-investment platforms	Asset tokens
Pros	No payback obligation	Low borrowing costs, High credit quality, Tax-free	Reliable funding source, Most applied	Direct access to the capital market	Direct ownership and management, Higher return	Expanded investor pool, Improved efficiency, Reduced counterparty risks
Cons	Subject to political uncertainty, Public deficits	Unattractive for investors due to low return rate, Default risks, Country risks	Highly fragmented, Multiple intermediaries, High costs	High upfront and fixed fees, High risks and volatilities	Limited liquidity, Expertise required, High upfront investment	Regulation uncertainty, Technical difficulties
Liquidity	*	***	*	***	*	***
Transaction efficiency	**	*	**	*	*	***
Transparency	*	***	***	**	*	***
Private participation	*	***	***	***	**	***

Note: ***, **, and * indicate high, medium, and low applicability, respectively.

by a select number of invited participants in a permissioned system. In the former, no entity or individual is capable of arbitrarily changing a distributed ledger. Furthermore, the consensus among the community provides a second layer of protection against data manipulation. Therefore, token transactions that take place on a blockchain are considered immutable. The legal rights and ownership of tokenized infrastructure assets are directly embedded in security tokens, and the owners of these tokens can participate in the decision-making process by exercising the voting rights that they gain along with their tokens. The identification of token sellers and buyers and the complete transaction records stored in a blockchain are immutable and easily traceable.

5 Case study: ZiyenCoin

ZiyenCoin is the first SEC-compliant oil and energy blockchain token issued by Ziyen Inc., a blockchain-pioneering company that plans to offer a maximum of 500 million equity-based security tokens backed by energy assets in its portfolio (Ziyen, 2019). Despite its limited contributions to the global infrastructure market, this five-million-dollar pilot tokenization project provides a potential solution to the shortfalls in global infrastructure investment if experimented successfully. The ZiyenCoin case is analyzed in this study to illustrate the infrastructure assets tokenization process. The associated benefits, challenges, and barriers of this process are highlighted in the Discussion section.

5.1 Issuer

Ziyen is a USA-based oil and gas producer that focuses on energy assets tokenization with the goal of developing new technology for improving energy production efficiency and liquifying energy assets. The equity of this company has been tokenized and issued as ZiyenCoin, which is offered for sale as a security token pursuant to SEC Rule 506(c) of Regulation D on a permissionless public blockchain. The first ZiyenCoin was mined on July 24, 2019. Since the initial date of STO, 213522450 ZiyenCoins have been issued to 47 investors. The first acquisition of 241 acres of oil and gas leases in exchange for 2300000 ZiyenCoins directly was subsequently announced on October 23, 2019. Ziyen has been actively building a public energy token trading platform to further deploy the implementation of blockchain tokenization in the energy sector and to advocate tokenization to the public.

5.2 Investors

ZiyenCoin is offered to both USA and non-USA investors. USA investors are required to be accredited as defined under SEC Rule 501 of Regulation D and should be verified by North Capital, a third-party escrow agent that ensures the token issuers and accredited investors involved in the STO process comply with federal, state, and any rules and regulations. Non-USA investors who participate in the STO of ZiyenCoin must comply with Regulation S under the Securities Act. However, non-USA investors are not required to be certified as accredited investors. As such, these investors face fewer limitations than USA investors under the current USA security rules. The minimum investment of each investor is 50000 ZiyenCoins, which is equivalent to $500.

5.3 STO

When a potential investor decides to invest in ZiyenCoin, a subscription agreement must be filed to Ziyen. Future token investors must be investigated by a KYC/AML service provider to ensure compliance with SEC regulations. When an investor is deemed qualified to invest in ZiyenCoin, Ziyen is notified by North Capital to mint and transfer a certain amount of ZiyenCoins to the token wallet of the company. After the investor’s fund is cleared, Ziyen initiates the token transfer, which requires the participation of a pre-qualified transfer agent. This transfer agent manages detailed transaction records containing the identifications of token owners and wallet addresses where tokens are stored and where to be stored. Afterward, the investor’s funds are released from his/her bank account or cryptocurrency wallet to the company’s accounts, and ZiyenCoin is then transferred from the company’s token wallet to that of the investor under the supervision of the transfer agent. The rights to the company’s Class A securities, incorporation certificates, and bylaws are embedded into the smart contract of each ZiyenCoin. All associated rights with the token are transferable among authorized investors in transferring and primary and secondary trading.

Records of token transactions are stored on the Ethereum blockchain and validated by nodes of the Ethereum network. Each node executes and records the same transaction into one block. The blocks are added individually in chronological order. ZiyenCoin in each wallet can be tracked through its address in the smart contract recorded on the blockchain. The public has access to source codes, transaction history, and contract details related to the token by navigating the address. The security rules and certain restrictions of the company are enforced into the smart contract of each token. The smart contract is coded in the Solidity programming language. The security token protocol of ZiyenCoin is provided by Polymath, which assists Ziyen in issuing, managing, and transferring tokens.

5.4 Tokens storage, trade, and transfer

5.4.1 Peer-to-peer transfer

ZiyenCoins offered in STOs are transferred to the ERC-20 token wallets of investors, who are then given a private key. This key interacts with the smart contract and allows token owners to transfer ZiyenCoins to other wallets that are either owned by secondary exchanges or certified individuals. Transfers are made via whitelist, which contains wallet addresses of pre-approved wallets. A whitelist is a separate smart contract that allows administrator-approved investors to transfer tokens. ZiyenCoins can be transferred within the whitelist with the assistance of the transfer agent. Whitelists that contain the wallet addresses of investors are regularly maintained in compliance with the requirements of KYC/AML and the laws, securities rules, and restrictions of Ziyen. Owners of ZiyenCoin must initiate a transaction to transfer ZiyenCoins. Afterward, the smart contract of ZiyenCoin determines (a) whether the transfer follows the programmed rules and (b) whether the destination wallet address is approved and included in a whitelist. As long as these conditions are met and the transaction satisfies the legal criteria recognized by the transfer agent, ZiyenCoin can be transferred from the ERC-20 token wallet of the initiator to the wallet of the transferee. Afterward, the transaction is registered in the transfer agent's system and recorded on the blockchain. Otherwise, the transfer fails.

5.4.2 Secondary market trading potential of ZiyenCoin

ZiyenCoins are presently not listed in secondary markets. However, Ziyen is establishing a new energy-asset-backed token trading platform for ZiyenCoin and other energy asset tokens. Besides, the management of Ziyen is considering listing ZiyenCoin on established security token exchanges, Open Finance and tZERO. To allow the secondary trading of ZiyenCoins, wallets of the secondary market must be added to the whitelist by the transfer agent. The token exchange is responsible for conducting KYC/AML and other required checks for its own customers and for adding the wallet addresses of these customers to ZiyenCoin's whitelist. Tokens are transferable among the wallets of individuals and the exchange as long as they are included in the whitelist. Figure 3 illustrates the tokenization process of ZiyenCoin.

6 Discussion

6.1 Token features

6.1.1 Liquidity

Pool of investors

The commitments and investment tickets of infrastructure assets are in the order of millions of dollars. The

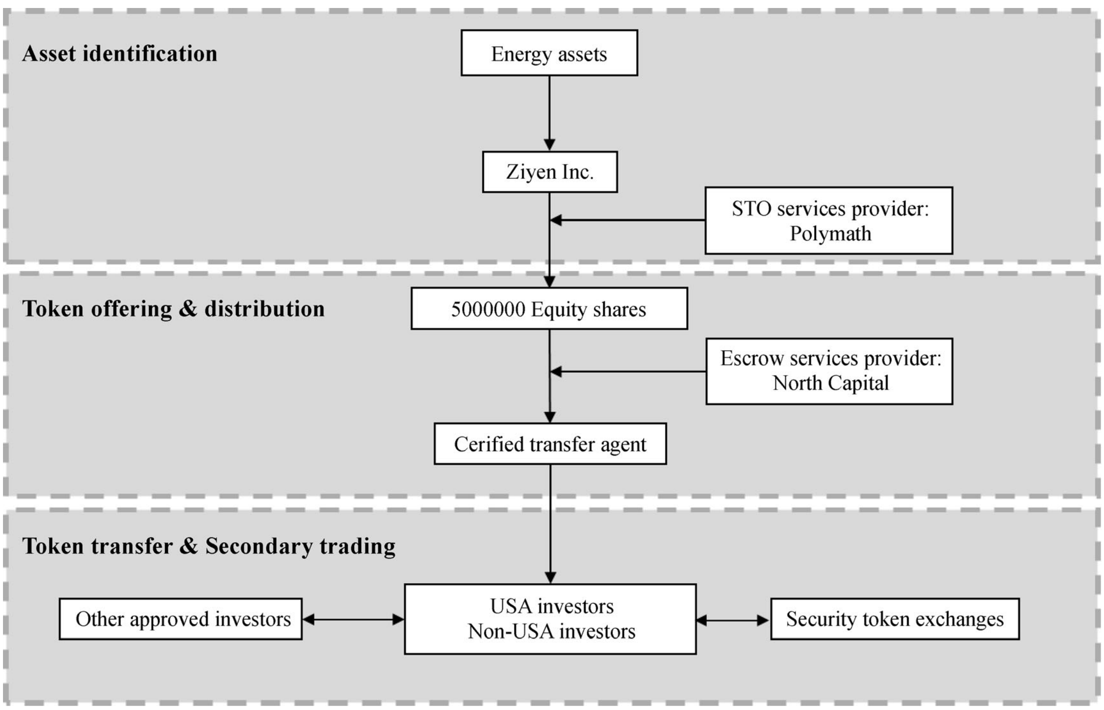

Fig. 3 Tokenization process of ZiyenCoin.

capital intensity of infrastructure investment limits the participation of small-scale institutional and retail investors. Tokenization creates a highly democratized investment platform. Security tokens are usually priced at a very low rate. In the case of ZiyenCoin, which is valued at $0.01, represents minuscule ownership of Ziyen's energy assets. This value lowers the initial capital requirements for investing in infrastructure assets, thereby allowing small investors to invest directly through small-value tokens—with investments of as low as 50000 ZiyenCoins—to become shareholders of Ziyen. Therefore, tokens enlarge the investor pool for infrastructure investment. Although Ziyen is an American company with assets registered in the USA, international investors are also allowed to invest in ZiyenCoin. The company has more than 370 investors from over ten countries. The participation of international investors expands the market from the domestic to the global level. From the investors' perspective, asset-backed and blockchain-derived tokens, such as ZiyenCoin, allow investors to allocate their funds to distinctive assets, to meet their investment profiles, and to build up a diversified portfolio.

Secondary markets

The tokenized private equity of Ziyen offers investors access to secondary liquidity. Although certain restrictions, such as lock-up periods, may apply, investors still benefit from trading ZiyenCoins to meet their liquidity needs. Historically, the private equity market is considered illiquid even though secondary markets exist and have been growing in sophistication due to the increased demand for liquidity on part of institutional investors and the growing number of fund managers who gain access to new streams of capital. Tokenized investment opportunities further open private equity capital, which suffers from insufficient liquidity (Lu et al., 2019). Ziyen is plan to launch its own energy trading platform, the ZYEN Digital Trading Platform, which tokenizes productive energy assets by using permissioned blockchain in the late of 2020. The anticipated users of ZYEN include energy asset investors and owners of renewable and carbon-based energy assets. The development of related technologies and tokenized investment communities over the past two years has increased the number of token exchanges. As of October 2019, 51 blockchain-derived token exchanges, platforms, or marketplaces have been established around the globe (Security Token Market, 2019). Binance, the largest cryptocurrency exchange in the world, announced its launch of a security token trading platform on September 2018 (Baydakova, 2018) and has since then inspired many other major cryptocurrency exchanges to follow its lead. With the emergence of well-established exchanges, both investors and infrastructure developers can gain easy access to such investment vehicles and financing sources, respectively.

6.1.2 Transaction efficiency

Transaction cost

The transaction costs for financing and trading infrastructure assets include pre-listing and trading costs, third-party credit rating requirements, and other costs associated with administrative needs. The initial public offering underwriter fee in traditional markets usually accounts for 4% to 5% of the gross proceeds, whereas small-cap clients are charged at an even higher rate (Marshall and Jack, 2018). Meanwhile, the transaction costs related to infrastructure asset public listings account for 15% to 22% of the total transaction value, whereas the costs associated with non-listed funds account for 10% to 15% (Uzsoki, 2019). In the ZiyenCoin case, each transfer of 1000000 ZiyenCoins costs 0.000185922 Ethereum tokens, which is approximately $0.03 at the current price of Ethereum. In sum, the transaction cost is lower than 0.0000001% of the transaction value. The transaction fees charged by security token exchanges are usually less than 1%. For instance, Binance, Huobi Global, Bitmax, and many other mainstream cryptocurrency and security token exchanges charge 0.25% transaction fees. Such superior efficiency can be ascribed to several reasons. First, traditional investment banking systems involve a significant amount of human capital, which requires a premium on their business deals. With the automation achieved by the smart contract on the blockchain, the degree of required financial and legal professional engagement has been minimized. Consequently, the cost burdens throughout the financing and trading process can be reduced. Second, incumbents in the finance industry have built up substantial economic incentives to maintain their dominant status and fee structures. In this way, the transaction costs can be reduced in a less-concentrated, innovative, and vanguard market, which can be realized through tokenization. Third, due to the infancy of the blockchain industry and its lack of solid regulations, the requirements for regulatory compliance are also low. Having fewer regulations corresponds to higher cost efficiency.

Transaction time

ZiyenCoin transactions have a median confirmation time of 36 s. Shorter transaction times result from the involvement of fewer intermediaries and a simplified transaction process. Blockchain transactions are executed on a peer-to-peer basis without a centralized clearinghouse. Given that trades are always matched, the delivery of underlying security tokens cannot be delayed. International bank wires within the SWIFT system usually take three to five days. The settling times for listed securities and blockchain tokens usually last for more than three business days and within a few minutes, respectively. Blockchain-derived tokens can be traded for 24 h for an entire week, while trading in traditional markets usually lasts for six to eight hours per day for five days a week.

6.1.3 Transparency

A significant degree of information asymmetry is recorded between infrastructure developers and investors, and such asymmetry extends the due diligence processes and the transaction time. The lack of transparency introduces challenges in the price discovery process and increases the amount of risks carried by participating parties. In the case of ZiyenCoin, the contract contents, wallet addresses of token owners, transaction histories, token supplies, and other essential information are stored immutably in the blockchain and can be tracked in real time. Improved transparency is one of the most significant advantages of a blockchain. After transactions are successfully performed, all relevant data become available to the public and can be queried at any time. The legal rights of tokenized infrastructure assets are directly embedded into security tokens. The identification of token sellers and buyers can be traced in immutable and complete transaction records stored on a blockchain, thereby significantly reducing the information asymmetry among counterparties involved in a transaction.

Lu et al. (2019) identified cash flow collection and channelling of infrastructure assets as two factors that lead to a successful financing arrangement. Transparent information disclosure is valuable for institutional investors who are considering investing in infrastructure companies or funds as an alternative asset class in their investment portfolio. Given the nature of blockchain technology, on-chain information cannot be manipulated unless an entity gathers over 50% of the overall computing power, which is unlikely in most cases. The combination of these features provides investors a reliable information disclosure and restoration mechanism.

Although transparency is established from the moment when information is stored in the blockchain, auditing mechanisms for the original information sources are still required. For instance, the cash flows generated from Ziyen's energy assets can be found on the chain and cannot be manipulated. However, raw data are still centralized and managed solely by the company. Without proper legislation, regulation, and third-party auditing, the first-hand cash flow information becomes prone to intentional manipulation before its storage in the blockchain. This off-chain issue needs to be carefully examined in order to guarantee the full transparency claimed by practitioners in the blockchain industry.

6.2 Barriers

6.2.1 Regulation uncertainties

Security tokens such as ZiyenCoin have not been approved or disapproved by regulatory authorities. Trading between blockchain cryptocurrencies and fiat currency has been banned in China, India, Egypt, and many other countries, and the regulators of other major countries continue to hold ambiguous attitudes toward blockchain tokens. Many governmental permits and approvals are only considered temporary at this moment. Potential investors should then proceed under the assumption that their tokens may not be listed publicly or sold for an indefinite period. Cross-border transfers are one of the significant benefits of tokenization, but the alignment of international and domestic regulations fails to support tokenization in the near future. Scams and hacks in unregulated token markets also discourage the public's involvement in tokenization, thereby preventing the long-term development and maturity of the token market. Nevertheless, if the regulations are too stringent, then the benefits of tokenization are undermined. The critical values of tokenization, including independence, decentralization, and democratization of finance, can be diminished under a strict centralized regulation (Chiu, 2018; Hacker and Thomale, 2018; Kaal, 2018).

6.2.2 Technical challenges

The technology infrastructure for tokenization has several weaknesses. As necessary technology infrastructures, token exchanges, smart contract models, programmers, and legacy systems, among others, are required to realize the stated benefits of tokenization. However, token issuers have to build certain key supporting infrastructure on their own. One of the main issues in the ZiyenCoin case is the lack of an end-to-end use of smart contracts in the energy sector. Ziyen has to make large upfront investments in programming smart contracts before tokenizing any assets. The blockchain system is considered safe and outperforms other systems by offering users with increased levels of data security. However, the applications of blockchain may be vulnerable to cybersecurity attacks. This problem has been addressed in the literature, which offers strong arguments for the capacity of the blockchain to enhance the resiliency of critical infrastructure systems, such as energy grids (Mylrea and Gourisetti, 2017), telecommunications (Kshetri, 2017), and smart cities (Mora et al., 2018). The potential malicious attacks that may impact infrastructure assets pose additional risks that token investors have to bear. Blockchain tokenization also has a tight labor market. To attract qualified technical personnel, companies have to offer decent wages, but doing so will increase operating costs and reduce their competitiveness.

6.2.3 Limited public awareness

While the concept of tokenization has aroused public curiosity, only few people actually understand such concept or participate in such process. Infrastructure asset tokenization still has a long way to go before the general public comes to know, accept, and participate in this process. Universal adoption of blockchain tokenization is impossible without a broad user base.

Most companies working on tokenization have been in operation for less than five years, and blockchain technology has only come to public notice over the past three years. The majority of the companies involved in this process are in their early stages of development and have been classified as start-ups. Ziyen and many other companies doing business in this field are subject to many risks common to such enterprises, including personnel limitations, lack of revenues, and restricted financial resources, and the risks associated with early-stage start-ups are eventually transferred to investors. Therefore, token investment remains risky in the short run.

6.2.4 Volatility

The offering of ZiyenCoin is not underwritten by banks similar to stablecoins, and the price of a token is arbitrarily set by the management. The current price, which is $5 million for 500 million ZiyenCoins, has also not been tested yet in the market. When the value of a company's assets gradually increases, oil refineries demonstrate an exponential production or a security token investment bubble forms, each ZiyenCoin may be worth much more than $0.01. Nevertheless, if the newly established company goes bankrupt or tokens are recognized illegal by new regulations, then ZiyenCoin may lose 100% of its value. The price of tokens has been extremely volatile in recent years. For instance, the Polymath Token (POLY) issued by Polymath, which is the security token technology provider for ZiyenCoin, has a negative 96.45% return on investment when purchased at the time of its launch. This price went down from $0.79 per token on February 1, 2018 to $0.028 on November 6, 2019. Some other security tokens, such as Swarm, BANKEX, and Prometeus, have lost as much as 99.5% of their initial offering value. By contrast, Ethereum, Bitcoin, and many others have received more than 6000% returns during the same period. Tokens are notoriously volatile, and such volatility, despite making some investors rich overnight, discourages most retail investors, institutional investors, and government-backed financial institutions from participating in the long-term. Without the involvement of these participants, token markets may have a very slim possibility of becoming mainstream.

6.2.5 Limited public sector adoption

The potential impact of blockchain technology on the public sector has recently been acknowledged by public agencies, governments, and industry providers. For example, the UK Government Office for Science states that the application of blockchain in the public sector can (i) enhance the protection of critical infrastructure and data, (ii) reduce operational costs, and (iii) improve the transparency and traceability of transactions (Government Office for Science, 2016). Other applications of blockchain include storage of health records (Estonia) and financial fraud prevention, which can help overcome the under-reporting of taxable gains by investors in countries where they do not legally reside (Hyvärinen et al., 2017). While e-government initiatives are gaining traction, no evidence shows that the public infrastructure finance sector is being disrupted by digital financing mechanisms beyond data security and management, often under the umbrella of "blockchain for good" or "data for the public good".

Given that 75% of infrastructure assets are in the public sector realm and due to the increasing adoption of new types of PPP, public financing models are expected to embrace digital financing and tokenization models. A recent Organization for Economic Co-operation and Development (OECD) report highlighted the value of blockchain in the green transitioning of economies yet notes "a general lack of education and knowledge regarding its principles and drawbacks is observed in the public market" (OECD, 2019). The application of new technologies, especially in untested markets, poses risks that need to be compared with benefits. Proper technical set-up is crucial to address the challenges in network scalability, processing speed, and security risks. Therefore, increasing fact-based knowledge and training relevant decision-makers are essential in fulfilling the potential of blockchain technology. Policymakers should then take the initial steps to address legal and regulatory issues related to the use of blockchain technology in infrastructure investment.

7 Conclusions

This study builds a conceptual framework for financing infrastructure assets through blockchain tokenization to highlight the opportunities for emerging technologies to disrupt financing mechanisms. Conventional infrastructure financing instruments are compared with blockchain tokenization by reviewing the literature on infrastructure project finance. A case study is performed to offer guidelines for infrastructure asset tokenization. Interviews with the management of Ziyen are also conducted to confirm various details that have been recorded in the case study. The key participants, regulations and rules, and procedures of the token offering process are illustrated in this guideline.

The benefits of infrastructure tokenization, including liquidity opportunities, the democratization of investments, reduced information asymmetry, and increased pricing and risk information disclosure, are discussed in the context of the case study. However, the potential of tokenization would not be fully realized because of the limited technical infrastructures, regulation uncertainties, and volatilities in the token market. Collaborative and collective efforts by entities, including governments, financial institutions, local communities, private companies, and individuals, are required to further develop this concept.

This research has several limitations. For instance, most of the use cases and investment models examined in this work are still in the pilot stage, thereby limiting broad summary statements. The examined use case focuses on infrastructure asset tokenization in the energy sector by using a permissionless security token. Future research can explore the tokenization process that uses other types of infrastructure (e.g., toll roads, pipelines, and airports) and tokens (e.g., utility tokens and stablecoins).

Similar to any other technology adoption and diffusion curve, the success of the transition to tokenization depends on the problems that need to be solved. When the potential risks and barriers to the broader application of tokenization are carefully examined and mitigated, the economy of tokenization will be leveraged by the ripple effects from the finance industry where tokenization is applied. Given the value proposition of democratized and performance-based financing, the world is poised to reap benefits from tokenization, such as closing the infrastructure financing gap and developing a capacity to upgrade the adaptiveness and resilience of infrastructure systems.

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