ASSET TOKENIZATION: A BLOCKCHAIN SOLUTION TO FINANCING INFRASTRUCTURE IN EMERGING MARKETS AND DEVELOPING ECONOMIES

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Abstract

Infrastructure is essential to alleviate poverty and generate long-term growth in emerging markets and developing counties (EMDEs). Financing of infrastructure in EMDEs is faced with government deficits, issues of transparency, and insufficient financial efficiency, as well as the lack of performance tracking. This paper explores the potential of tokenization and to mobilize broader private sources to bridge the widening infrastructure gap. Tokenization would elevate the private sector's confidence and enthusiasm via improving infrastructure asset liquidity, opening access to small-scale projects, and enlarging the group of investors to participate in EMDE infrastructure development. From the EMDE governments' perspective, administrative and financial efficiencies can be improved through automated auditing, enhanced project monitoring, and lower financing costs brought by the asset tokenization. Four case studies are presented to illustrate the asset tokenization process and define benefits brought by the emerging technology in the context of public finance and private finance. Regulatory and technical risks at present are identified. Implications for EMDE policymakers and international organizations, such as multilateral development banks, to initiate coordinated efforts to facilitate the widespread adoption of infrastructure asset tokenization in EMDEs are presented in the research. Once the potential risks and barriers for broader applications of tokenization are carefully examined and mitigated, the impact would transform both economies and people's life in EMDEs.

Keywords: infrastructure finance, blockchain, asset tokenization, public-private partnerships, emerging markets and developing economies

1. INFRASTRUCTURE GAP IN EMERGING MARKETS AND DEVELOPING ECONOMIES

Infrastructure assets and services for the well-being of societies are a fundamental to social progress and economic growth by facilitating trade, increasing productivity, and encouraging innovation (Inderst and Stewart 2014; Subhanij and Lin 2018). In Emerging Market and Developing Economies (EMDEs), infrastructure is essential to alleviate poverty, accommodate population growth, and manage the pressures of increasing urbanization (Straub 2008). Investment in infrastructure is set to be one of the main drivers to generate long-term growth and stimulate economies out of recession after a systemic crisis like the COVID-19 pandemic (Wood 2020).

Despite the fact that infrastructure is at the nexus of economic prosperity, social welfare, and national security, there is an increasing mismatch between the need for more and better infrastructure and available financing globally (Rokicki and Stepniak 2018). The McKinsey Global Institute (MGI) forecasted that the world would need to invest $3.7 trillion per year in infrastructure through 2035 to accelerate economic growth and realize sustainable development (Woetzel et al. 2017). An analysis by MGI showed that the biggest infrastructure financing gaps are in Indonesia and Mexico, while Brazil, India, Saudi Arabia, and South Africa also face significant gaps. According to the Asian Development Bank (ADB), the infrastructure investment requirement for 24 representative developing countries, excluding China from 2016 to 2020, is 8.2 percent of the Gross Domestic Product (GDP). Nevertheless, the current investment only accounts for 3.2 percent of the GDP. The gap is as large as 5 percent of the representative counties' GDP (Subhanij and Lin 2018). The World Bank estimates that EMDEs need to triple the current annual spending in infrastructure over the next decade (Mapila et al. 2017). The demand for investment in infrastructure in EMDEs will only increase along with time to meet the United Nations' (UN) Sustainable Development Goals (SDG) (Waage et al. 2010).

EMDE infrastructure has been traditionally financed, delivered, and managed by the public sector. Public funding through direct grants, subsidies, and low-interest (concessionary) loans account for seventy percent of total infrastructure investment in EDMEs (Kim 2016). The contribution from the private sector amounts to approximately twenty percent (Inderst and Stewart 2014). The last ten percent is supported by Multilateral Development Banks (MDBs) (Delmon and Delmon 2013). Public budgetary constraints, tighter financial regulations (e.g., Basel III), and reduction in long-term bank loans have dwindled the traditional sources of capital to support infrastructure. This situation incentivizes EMDE governments to unlock private capital through public-private partnerships (PPPs), in an effort to bridge the widening financing gap. While the current private participation in infrastructure is limited due to mismatches between risk-return profiles of projects and available capital, the opportunity for growth is clear. Only about one percent of institutional investor assets are allocated to direct infrastructure investments globally (OECD 2013; Inderst 2013). The allocation in EMDEs is even less. The foremost impediment to greater private investment in infrastructure is not the lack of available funding. Capitals are seeking long-term, low-risk, and inflation-adjusted returns, which can be provided by infrastructure investment under the low-interest-rate environment are ample (Ehlers 2014). The problem is rather how to match the abundant supply of private capital with the demand for infrastructure.

Conventional infrastructure financing faces limitations in enabling cross-border transactions with adjusted risks, generating comprehensive operational performance data, and financing of small and medium-sized projects (Walter 2016). The existing infrastructure financing instruments and vehicles are illustrated in Table 1. In addition, traditional financing excludes the participation of individual investors, which impedes public finance to reach its full potential and hampers private participation in EMDE infrastructure development (Tian et al. 2020a; Inderst 2013). Pioneering thinking and groundbreaking financial instruments are required to ameliorate the public sector's engagement, enhance project governance, improve public finance efficiency, and mobilize broader private sources to bridge the widening infrastructure gap in EMDEs.

Table 1: Taxonomy of infrastructure financing instruments and vehicles

<table>
<tr><th colspan="2">Modes</th><th colspan="2">Infrastructure Finance Instruments</th><th>Market Vehicles</th></tr>
<tr><th>Asset Category</th><th>Instrument</th><th>Infrastructure Project</th><th>Corporate Balance Sheet/Other Entities</th><th>Capital Pool</th></tr>
<tr><td rowspan="4">Fixed Income</td><td rowspan="3">Bonds</td><td>Project Bonds</td><td rowspan="2">Corporate Bonds, Green Bonds</td><td rowspan="3">Bond Indices, Bond Funds, ETFs</td></tr>
<tr><td>Municipal, Sub-sovereign bonds</td></tr>
<tr><td>Green Bonds, Sukuk</td><td>Subordinated Bonds</td></tr>
<tr><td rowspan="2">Loans</td><td rowspan="2">Direct/Co-Investment lending to infrastructure project, Syndicated Project Loans</td><td>Direct/Co-Investment lending to infrastructure corporate</td><td>Debt Funds (GPs)</td></tr>
<tr><td>Syndicated Loans, Securitized Loans (ABS), CLOs</td><td>Loan Indices, Loan Funds</td></tr>
<tr><td>Mixed</td><td>Hybrid</td><td>Subordinated Loans/Bonds, Mezzanine Finance</td><td>Subordinated Bonds, Convertible Bonds, Preferred Stock</td><td>Mezzanine Debt Funds (GPs), Hybrid Debt Funds</td></tr>
<tr><td rowspan="2">Equity</td><td>Listed</td><td>YieldCos</td><td>Listed Infrastructure & utilities stocks, Closed-end Funds, REITs, IITs, MLPs</td><td>Listed Infrastructure Equity Funds, Indices, trusts, ETFs</td></tr>
<tr><td>Unlisted</td><td>Direct/Co-Investment in infrastructure project equity, PPP</td><td>Direct/Co-Investment in infrastructure corporate equity</td><td>Unlisted Infrastructure Funds</td></tr>
</table>

Sources: OECD (2015) (modified from Tian et al. 2020b)

2. INFRASTRUCTURE ASSET TOKENIZATION

Infrastructure asset tokenization refers to the process of tokenizing listed equity of infrastructure companies or funds, private equity of the special purpose vehicle (SPV) owning the infrastructure facility, or debts (loans and bonds) issued by project sponsors. Tokens representing ownership interests in infrastructure assets are considered to be digitalized securities, which are subject to security regulation. The investors can be institutional or retail, or a combination thereof as on the convergence platform (Herweijer et al. 2018), which seeks to facilitate the blending of finance for infrastructure projects.

Since the emergence of blockchain technology, its application to solve problems for industries across multiple sectors has rapidly grown (Sharma et al. 2019). Asset tokenization, one of the most prominent use cases of blockchain, has shown great potential to overcome current constraints on public and private finance. Tokenization enables the digital representation of assets on distributed ledgers or the issuance of securities in the tokenized form (Hileman and Rauchs 2017). The process allows for the conversion of the economic value and ownership rights derived from underlying assets in the off-chain real world into digital tokens on the blockchain (OECD 2020). Given the increasing transitioning of infrastructure to intelligent systems, and the desire to unlock efficient financing, blockchain-based tokenization may serve to support alternative financing models to overcome obstacles in EMDE infrastructure development. (Curry et al. 2006; Kyriakides and Polycarpou 2014). The rationale is that data derived from infrastructure use and performance results not only in uncovering operational efficiencies, but further has the capacity to unlock new revenue streams for third parties planning on building new services, and facilitates capital appreciation opportunities from identifying intangible values such as tracking of SDG. All three value pools can be transacted and embedded in automated contractual agreements.

Digital tokens backed by underlying infrastructure assets are governed and executed through a smart contract. The smart contract is a self-enforcing and self-executing contract with terms of the agreement by parties written into lines of code existing with the blockchain network (Buterin 2014). Through a smart contract, tokens can be transferred to investors without any intervention of intermediaries once contract terms (e.g. performance metrics based on the value pools) are met. Relevant financial information is simultaneously recorded onto blockchain immutably. Contractual terms and historical data in smart contracts are accessible and visible, which brings transparency, accuracy, and efficiency to participating parties. The comparison of conventional infrastructure financing instruments with asset tokenization is illustrated in Table 2. By integrating stablecoins (e.g., synthetic central bank digital currency or sCBDC) serving as a means of payment and store of value, instead of fiat currency, in the transaction and management of digital tokens, efficiency brought by tokenization would be further improved by orders of magnitude, considering stablecoins and tokens are in the same blockchain ecosystem (Shirai 2019).

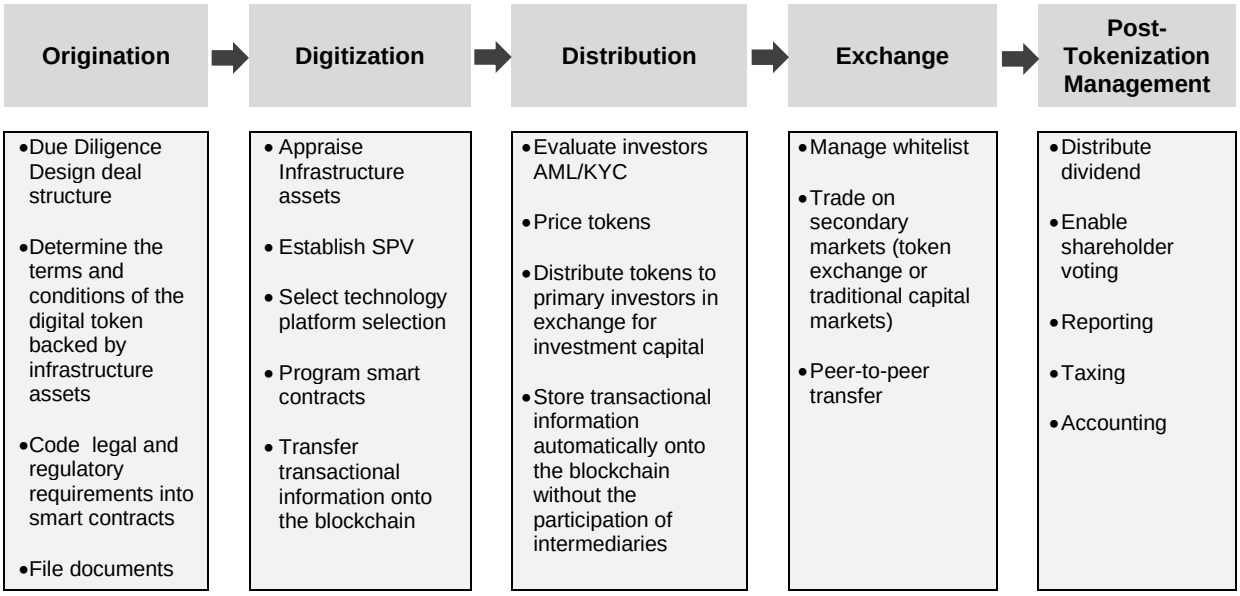
Table 2: Comparison of Conventional Infrastructure Financing Instruments with Asset Tokenization

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: ***indicates high applicability; ** indicates medium applicability; * indicates low applicability.
Sources: Tian et al. (2020b).

Typically, the first step towards the tokenization of infrastructure is to price and audit underlying assets. Risk and return expectations of the investment in the facility need to be well understood, as does the potential for revenue streams and cash flow uncertainties. Smart contracts are generated to address requirements and regulations. After the legal and deal structures for asset tokenization are established, asset token (security token) issuance services provider, Know Your Customer/ Anti Money Laundering (KYC/AML) vendor, custodian, primary/secondary marketplaces are determined and confirmed subsequently (Lootsma 2017). The management of the SPV sets the prices and trigger values for asset tokens. Potential investors need to pass AML/KYC checks to get accredited before investing. Once all the aforementioned processes are completed, newly minted tokens are transferred to wallets of accredited investors or get listed on public exchanges. Accredited investors are able to transfer their tokens to other accredited investors or trade these tokens on secondary markets. Future dividends and interest payouts generated from tokenized assets are sent out to wallets of token owners in the form of cryptocurrencies or equivalent fiat currency. The infrastructure asset tokenization process is illustrated in Figure 1.

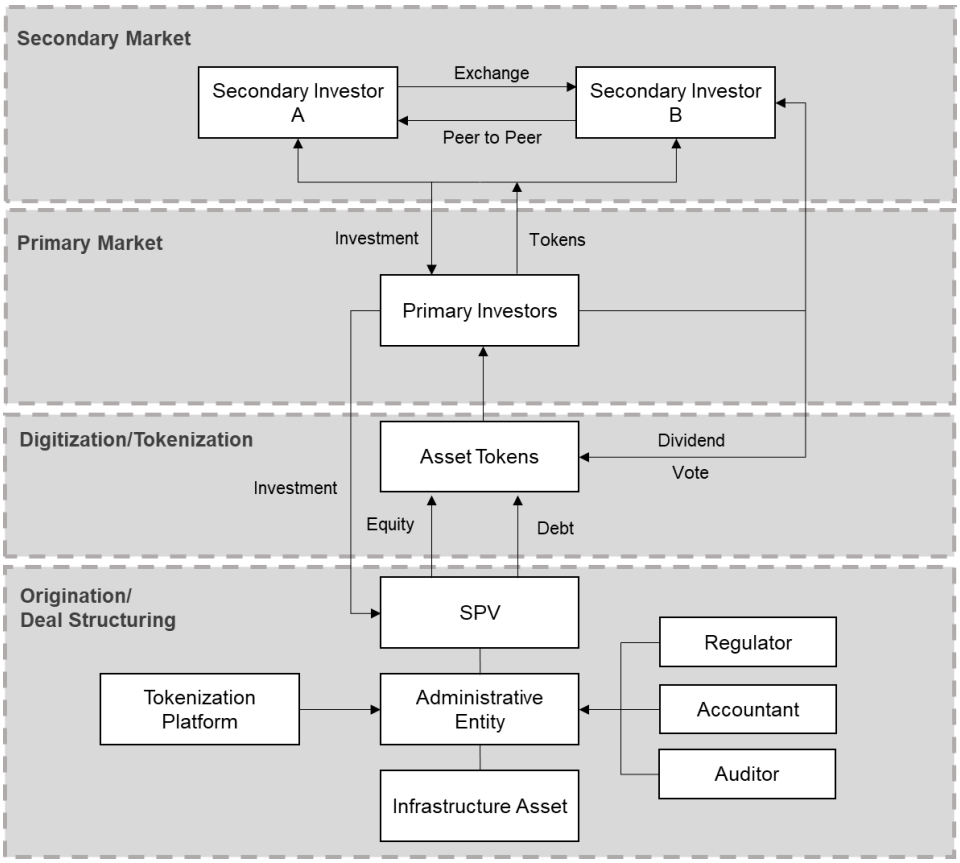
Figure 1: Infrastructure Asset Tokenization Process



Sources: Authors

Tokenization has the capacity to mitigate some of the limitations that are inherent to traditional infrastructure financing, including cross-border currency fluctuations risk impacting the bankability of projects, tracking of operational performance metrics, and broader participation of investors in projects. The transactional flowchart of infrastructure asset tokenization is illustrated in Figure 2. But it does introduce new issues that need addressing, such as overuse of computational infrastructure, speculative arbitrage as a result of unclear regulatory frameworks for issuance and compliance enforcement, and community participation in overcoming potential privacy infringement issues. Benefits and challenges associated with infrastructure asset tokenization in EMDEs are analyzed in detail in the following sections.

Figure 2: Transactional Flowchart of Infrastructure Asset Tokenization and Trading



Sources: Authors

3. TOKENIZATION AND PUBLIC FINANCE

3.1 Government's Perspective

The traditional funding sources of EMDE infrastructure are government budgets, bank loans, and international donations (World Bank 2019). Even though the private sector is playing an increasing role, the majority of infrastructure financing is still in the public domain. Challenges associated with public finance for infrastructure include inefficiencies in selection, structuring and procurement, and over-leveraged balance sheets, are considered the most (Kim 2016). The lack of confidence in EMDE governments executing on their commitments to co-financing has resulted in driving up borrowing costs up to six percent (Inderst and Stewart 2014). Other challenges include limited transparency, layers of intermediaries, and high financing costs have hindered the public sector in EMDEs to administrate and finance infrastructure projects efficiently. There is an urgent need to structure a model that would allow for policymakers to streamline financing models, risk transfer guarantees, and administrative requirements.

3.1.1 Administration

Corruption caused by the lack of transparency in government is a serious issue in EMDEs (Olken and Pande 2012). Bribes result in lower quality of infrastructure and make the government budget merely benefit a small group of people who have close relationships with authorities instead of the general public. High administrative costs, lack of accountable financial and operational data to support decision making, limited audibility, and noninteroperable database are challenges faced by the EMDE government in infrastructure public finance. To address the aforementioned challenges, a trustworthy, transparent, and sustainable system is necessitated, where tokenization may provide a viable option.

Through tokenization, administrative requirements and regulatory policies can be programmed into smart contracts, which are enforced automatically (Yu et al. 2017). Even though tokens backed by EMDE infrastructure assets are available to be traded on secondary markets or peer-to-peer raising no issues technically, certain forms of trading might be against regulatory requirements. Regulators can set restrictions coded into smart contracts based on domestic laws and regulations to block investors who fail to meet requirements to facilitate sustainable and secure development (Underwood 2017). The dissemination of information and governance rules are automatic and immediate on the blockchain (Liu and Xu 2018). Public entities such as infrastructure project administrators are able to capture and view real-time information of transactive activities on the blockchain. If restrictions are turned off or modified, the administrator would be notified instantly. Completed transaction history, investors' identities, digital wallet addresses, and other financial data are recorded immutably (Peter and Panayi 2016). The administrative system built on the blockchain through tokenization is able to track financial and operational data of infrastructure in an integrated manner in real-time. Infrastructure performance data such as usage and payments are stored on the blockchain with the help of smart meters. Timely and accurate data supports better decision-making of project administrators. Governments, project sponsors, project administrators, financial practitioners, investors, and citizens can monitor financial and performance information through data stored on the public blockchain. Tokenization also enables the automation of accounting, tax, and audit processes. The automation and better transparency brought by tokenization would reduce administrative costs and related risks to improve administrative efficiency.

> Vignette 1. The Malawian kwacha token is a type of utility token used in a hospital project (CoreLedger 2019). Instead of releasing construction fees to the contractor directly in the traditional way, this project implements tokenization to prevent corruption and to improve administrative efficiency. At first, project sponsors convert capital into dollar tokens. Then dollar tokens are converted to Malawian kwacha tokens managed by an administrative organization. Service tokens are issued by the contractor, which are backed by a specified amount of construction services. Predefined rules to release funds to compensate for construction work are coded into smart contracts. A local sponsor representative named by the administrative organization decides whether the contractor's work is completed per specifications, but the project funds do not go through the local representative. Once the work is completed and confirmed by the representative, it triggers the smart contract to purchase the contractor's service token with Malawian kwacha token to pay the contractor instantly without any delays. Tokenization reduces intermediaries and ensures the funds to go to the party who performs the service but are not lost due to corruption and fraud activities during the exchange processes between the parties. On the other hand, project

sponsors obtain the transparency to monitor real-time capital flow and construction process.

3.1.2 Finance

Public finance for infrastructure is fully leveraged (full faith and credit of the issuing agency) with no at-risk equity capital, through debt financing (loans or bonds) in most cases (Kim 2016). The cost of public debt financing is lower than the private sector's since public assets and taxes, which are considered low risk, can serve as collateral, and because the issuances are tax-free for investors (Isin 2018). However, the cost of debt issuances, settlement, clearing, and safekeeping are still conducted through the conventional financial system (Lin 2016). The expenses are eventually transferred to project sponsors and off-takers, if possible, but they are fully backed by the government. Besides costs, a full understanding of counterparty risks, risk allocation strategies, and ambiguity of performance and operational data also affect the effectiveness of infrastructure finance. Internal government transfer in the form of subsidies and direct grants to fund infrastructure is critical in EMDEs, while the reconciliation process under the current system is expensive and time-consuming (Onwonga et al. 2017). A significant amount of unreconciled funds can't be used at any given time.

A blockchain-based accounting and payment system would reduce the dependencies on the conventional manual process (Dai and Vasarhelyi 2017), facilitate intergovernmental transfers, and unlock trillions of unreconciled funds (Godambe and Samudrala 2017) into infrastructure development without additional external capital resources. Raising capital through government bonds and commercial bank loans are two primary options to finance infrastructure in EMDEs. Tokenization has the potential to introduce benefits for both financing options as blockchain-based transactions would serve as a tamper-proof audit trail of contractual agreements and an immutable and transparent information source among involved parties (Ducommun 2019). Activities and information are managed in a distributed manner. Improved transparency and reduced risk are expected to facilitate the rating of tokenized EMDE government bonds. The roles of banks in managing investor relations and in market-making will no longer be required since smart contracts can handle automated issuance and distribution. Blockchains can also fractionalize complex and bulk debt instruments to clarify the relationships between larger pools of investors. According to (HSBC and SDFA 2019), the issuance cost for tokenizing a typical green bond with a twenty-year maturity and a par value of $100 million is $693,000, which accounts for roughly 10% of the $6,449,000 in the standard process. If network scalability can be improved, the cost reduction and efficiency gains will be more significant.

> Vignette 2. Belarus 252/USD is the first tokenized government bond issued by the Republic of Belarus and offered on the token exchange currency.com (currency.com 2019). The nominal value of the underlying tokenized bond is $1,000, with a 4.2% annual yield to maturity. Users of the token exchange can invest in the tokens using fiat currency or cryptocurrencies, such as Bitcoin and Ethereum. Fractional tokens with a value of less than $1,000 are available for trading, which increases the liquidity and enlarges the investor pool to participate in the bond sales. From the token issuer's perspective, lower issuance cost, automated distribution, and better transparency improves the overall efficiency of the process. The case of the Belarus 252/USD proves the feasibility of utilizing tokenization for government debt financing. EMDE governments could experiment

tokenization in other forms of debt financing based on lessons learned of this project to realize better public finance for infrastructure.

3.2 Multilateral Development Bank Perspective

MDBs play a significant role in infrastructure project development and innovation in EMDEs (World Bank 2019; ADB 2020; Weiss 2017). In part, this is because MDBs contribute as a funding source through syndications or co-financing to improve the creditor status of partners and because the funding builds confidence in projects and markets to catalyze other forms of (public and private) investment (Sharan et al. 2007). MDBs can also facilitate infrastructure investment and operation by providing technical support and assisting host nations to improve their policy and regulatory environment (Middleton 2007). However, some critics have argued that MDB operations are not transparent (Zimmermann and Fariello 2012). Additional obstacles faced by MDBs including the high cost of capital in low-rated countries (high credit and political risk), difficulty in handling complex deals involving multiple parties, local financial capacities, scattered databases, foreign exchange risk, and regulatory burdens. These challenges continue to impact these organizations from achieving their full potential to support infrastructure projects in EMDEs.

Asset tokenization would be a powerful instrument for tracking data to enable donor countries, MDBs, and borrowing countries to monitor the project-specific financial and operational process. Transfers of financial resources are immutably stored on the blockchain and open for review to the public or accredited partners, depending on whether the blockchain is permissioned or permissionless (Sato 2018). Third-party review increases public confidence in the credibility of EMDE project sponsors, MDBs, and projects themselves, and may incentivize private sector partners to participate (Panisi et al. 2019). By introducing stablecoins or by utilizing cryptocurrencies in fundraising and cross-border fund transfer, currency risks, and foreign exchange risks would be largely mitigated (Kondova et al. 2020). On the other hand, stablecoins or cryptocurrencies as native tokens on the blockchain would drive more efficiency gains in infrastructure asset tokens issuance, transfer, trading, and management. Through tokenization, it becomes possible to initiate and build a global standardized interoperable database on the blockchain, which enables a larger group of participants to interact and gain access to data in a frictionless manner without intermediaries (Kshetri 2017). A hybrid globalized system, which complies with target countries' regulation and particular requirements, at the same time seamlessly aligns on a global level built on smart contracts, can be realized through tokenization with the support of MDBs.

Vignette 3. Bond-i is the world's first tokenized bond issued by the World Bank (Commbank 2019). The bond is managed through its lifecycle on the blockchain. Automation is enabled by smart contracts for issuance, clearing, and custodianship on a permissioned Ethereum blockchain to reduce intermediaries and lower transaction fees. Data reconciliation is not needed as long as market actors have access to the same ledger. By allowing for Proof-Of-Authority (PoA) consensus, the World Bank could authenticate and give target investors access to the system as long as they meet the requirements. It enhances security, and at the same time, brings new market participants to the table, including offshore investors. A node with observer's privileges would grant the World Bank and regulators direct access for full visibility of transaction records and real-time reported data, thus improving transparency and communications between market participants and

the bond issuer. Other benefits include faster processing for investors and secure holding without custodians. Bond-i was offered in secondary markets. Pilot initiatives such as Bond-i are just the beginning. Implications for MDBs by levering the technology to facilitate EMDE infrastructure development are discussed in Section 6.

4. TOKENIZATION AND PRIVATE FINANCE

According to McKinsey, more than $2 trillion investment in infrastructure is needed per year for developing countries to fuel projected GDP growth, while governments in these countries are continuously facing budgetary constraints to allocate public funding to support infrastructure (Hussain et al. 2019). Private capital plays an increasingly important role in facilitating infrastructure investment (Hussain and Siemiatycki 2018). Private investors not only facilitate infrastructure financing but also help to improve the efficiency in construction, operation, and maintenance. However, through conventional financing models, the investment in this asset class is limited to a narrow set of large institutional investors, leaving a significant amount of other forms of private capital on the sidelines. Small-scale investors or retail investors have been historically excluded from infrastructure investment (Regan 2017). Other obstacles, such as information asymmetry on projects, the scale of investment, financing costs, and country (political) risks, add to the cost of capital, discouraging a wider group of private investors from participating in EMDE infrastructure (OECD 2020; Della Croce 2011). Alternative financing instruments and operational models capable of efficiently utilizing diverse capital resources (‘different capital stacks’) are needed to bridge the current EMDE infrastructure gap (Della Croce and Yermo 2013).

4.1 Liquidity

On account of a narrow set of private investors, limited trading options on secondary markets, cross-border trade barriers, infrastructure assets are considered to be illiquid (Blanc-Brude 2014). Limited partnerships in infrastructure funds are normally locked in for five to seven without direct exit strategies (Uzosoki 2019). The illiquidity discount applied to assets where contracts have a prohibition of sale clause is estimated between 20% and 30% of the net value of infrastructure assets. In some cases, the illiquidity discount can be as high as 60%, reflecting the perspective off market participants. In emerging economies, the illiquidity premium tends to be higher because of greater systemic risks, higher inflation and lower frequency of trades in general (Amihud et al. 2015). There is no doubt that illiquidity risk is one of the major hurdles that discourage the private sector from investing in infrastructure. Tokenization could improve the liquidity of infrastructure assets in EMDEs by facilitating trading in secondary markets and unlocking global markets to capture the lower cost of capital and higher return from this illiquid asset class.

4.1.1 Global exposure

A considerable portion of private capital sources for EMDE infrastructure comes from international investors owing to domestic capital markets being less regulated and relatively underdeveloped (Inderst and Stewart 2014). However, difficulties with cross-border transactions and high transaction costs associated with the traditional financial system have created obstacles to attract foreign capital. By allowing for the atomicity of transactions via hash time locked contracts (HTLC), blockchain-based tokenization platforms remove geographical restrictions and enable automated

KYC/AML verification, which allows global participants to become involved and facilitates secure transactions to happen anywhere and anytime (Decker and Wattenhofer 2015). This type of contract is time-constrained conditional payments to be executed only when predefined conditions are met within a specific timeframe. Asset tokenization enables EMDE infrastructure sponsors to raise funds in global markets, grants international investors access to invest in EMDE infrastructure, and allows EMDE investors to pursue high-quality infrastructure assets worldwide. Exchange rules of the underlying asset ownership associated with tokens can be programmed in the smart contracts to comply with global and local regulations. Only accredited purchasers and sellers are able to complete the transactions.

4.1.2 Secondary trading

Through asset tokenization, illiquid EMDE infrastructure assets are converted into liquid digital tokens (security tokens), which can be traded twenty-four hours a day and seven days a week in on-chain secondary markets or in traditional capital market exchanges that allow trading of security tokens. Efficient secondary markets enable accurate price discovery of infrastructure assets and promote the further generation of capital. Access to secondary trading supports investors to identify market trends of infrastructure sub-sectors and to rebalance portfolios in an instantaneous and even completely automated manner (Pethe and Ghodke 2002). On the other hand, digital tokens allow peer-to-peer trading among market participants by utilizing escrow accounts on the blockchain (Takahashi 2017). Tokens backed by infrastructure assets are transferable between infrastructure investors' wallets directly as long as such transfers have no constraints with regulations and contractual agreements. Secondary trading also gives rise to derivatives building on top of the digital tokens, which makes other value-added services to be realized. Currency risk is considered to be one of the major risks hindering private participation in EMDE infrastructure investment (Verdouw et al. 2015). By hedging currency risks through tokens derivatives, EMDE infrastructure could turn out to be more attractive to international investors. ZYEN is the first trading platform for security tokens backed by infrastructure assets in the energy sector (Tian et al. 2020b). Owners of energy assets and Investors worldwide could sell and purchase tokens through the platform promptly to raise funds or invest in energy infrastructure.

4.2 Transparency

Information asymmetry is a central issue in infrastructure development from the procurement process to the operation and maintenance phase (Ohashi 2009; Estache and Iimi 2010). Information and data required by the private sector to understand the risk of the project are opaque and highly scattered. Besides, the complicated and highly bespoke nature of infrastructure investments requires substantial investor resources to understand and manage relevant risks. Information asymmetry is more prevalent in EMDEs, due to less developed corporate governance, unprotected minority shareholder rights, weak insider trading laws, and unlevel playing fields for foreign investors (Ciner and Katagozoglu 2008). Information asymmetry has the risk of giving rise to widespread corruption, inadequate governance, and unfair competition, which further demotivates the private sector to participate in EMDE infrastructure investment (Burguet and Che, 2004). Moreover, there tends to be a lack of credit culture in infrastructure operations, hindering private investors from investing in EMDE infrastructure (Inderst and Stewart 2014).

Tokenization affords improved transparency (Wang and Kogan 2018). Asset tokens are backed by a distributed database, which is owned democratically by nodes all over the world either in a permissionless system or by a select number of invited participants in a permissioned system (Cash and Bassiouni 2018). In the former, there is no entity or individual capable of altering a distributed ledger arbitrarily. The permissioned blockchain, on the other hand, has been tested and has seen some adoption among institutional investors in pursuit of efficiency improvements in their transaction processes. The existence of a consensus among the permissioned community provides for a second layer of protection against data manipulation. Consequently, token transactions and underlying data on the blockchain are considered immutable and transparent.

Tokens are capable of incorporating operational and financial information on infrastructure projects. Data generated via smart metering and other 5G devices (Huh et al. 2017), such as sensors installed on infrastructure facilities to monitor operations, can be automatically recorded on the blockchain. Besides, complete on-chain transaction history, identification of the tokenized market participants, and frequency of maintenance are recorded and viewed by Investors, who gain direct visibility of performances of digital tokens and the operation of the underlying facility in real-time. The unprecedented data streams would make project finance modeling more accurate to predict the value of the underlying infrastructure assets (Uzosoki 2019). Improved accuracy in the valuation and cash flow forecasting would reduce contingency set aside for construction, and reduce the size of working capital credit facilities, thus contributing to a lower cost of capital and arguably higher valuation of the infrastructure asset. Furthermore, the improved quality and quantity of operation and financial performance data has been shown to shorten the due diligence process and elevate private investor confidence in the infrastructure project opportunity (Dudder and Ross 2017). Taken together, blockchain tokens increase the bankability of EMDE infrastructure projects, which further increases the attractiveness of these assets to private and international capitals.

4.3 Efficiency

Higher financing costs and complicated counterparty relationships are reasons hamper private investment in EMDE infrastructure (Estache 2003). The majority of financial instruments available in the market have been criticized for low efficiency due to high finance fees, prolong settlement and clearing process, the involvement of multiple layers of intermediaries, misalignment with the performance attributes of infrastructure assets, which have struggled to close widening infrastructure gap in EMDEs (Croce et al., 2015).

Smart contracts allow the two-way instant transfer of funds and tokens by removing intermediaries without the need for a separate settlement process (Conoscenti et al. 2018). The instantaneous settlement is realized by implementing HTLC to execute atomic swaps. The automation enabled by smart contract brings the potential to reduce the cost of token issuance and administration, increase the speed of execution, and facilitate dividend distribution, escrow management, and collateral management1 (Marco et al. 2020). Token transactions are trusted among the nodes participating in the network in a distributed manner. The reliance on centralized intermediaries is no longer needed to validate relationships among counterparties. Through the disintermediation process, the counterparty risks are reduced (Kakavand et al. 2017). As a consequence, the counterparty risk premium will be significantly lowered. Smart contracts also enhance governance by encoding contractual agreements into predefined conditions. Unless considers were met, the

smart contract would not be executed. Through conventional models, if a contract is breached, the counterparty can file a lawsuit and take legal actions. However, not only is it time and cost consuming but also impractical in some cases for international investors to protect their legitimate rights and interests in EMDE infrastructure investments in the view of cross-border, political, and other uncertainties. The efficiency gained through tokenization would be passed on to both public and private sectors and eventually promote EMDE infrastructure investments and boost the economy of the local community with wider benefits for the public.

4.4 Small-scale projects

Limited access to capital markets is a major barrier associated with financing small-scale infrastructure in EMDEs (Uzosoki 2019). Whereas part of the reason is the immature capital market in EMDEs, another reason is that private financing is only economical beyond a certain project size due to the involvement of intermediaries and other fixed financing costs (Adigwe 2012). This explains why small-scale EMDE infrastructure tends to depend on public finance when governments are facing fiscal pressure from overleveraged balance sheets. While small-scale infrastructure is affected the most, these projects always deliver the highest social and economic benefits per unit, as compared to large projects. Hence, solutions are necessary to address the financing deficit for smaller projects.

Through asset tokenization, a large number of intermediaries, such as banks, rating agencies, insurance providers, interest swap providers, are removed from the financing process, resulting in lower a series of fixed financing costs. The project scale is no longer a determining factor in cost efficiency. Tokenized small-scale infrastructure assets are tradable in on-chain token exchanges. Investors are granted access to invest in infrastructure regardless of the project scale (OECD 2020). Aside from tokenization, securitization provides another option to involve private investors in funding small infrastructure projects (Chang 2020). However, the asset-selection and the pooling nature of securitization reduces the direct engagement between a particular EMDE infrastructure project and a specific group of investors. Tokenization makes investment in small-scale infrastructure at the project level possible. It links up small projects and investors directly.

4.5 Retail investors

Infrastructure as an asset class is only accessible to institutional investors owing to high transaction costs, high minimum investments, and rigorous client suitability requirements because of the illiquid nature of infrastructure. Retail investors have been excluded from investing in infrastructure in both developed countries and EMDEs (Kim 2016). To facilitate small-scale transactions in a frictionless manner under the current financial models is challenging. (Walter 2016). It is the retail investors, as an untapped source of financing for infrastructure, who have the potential to transform the infrastructure financing landscape and accelerate infrastructure development in EMDEs.

4.5.1 Diversified Investment

Theoretically, a digital token can represent fractional ownership of any infrastructure assets or associated financial assets in the traditional form (equity, bond, loans, and derivatives) transferred

onto the blockchain (OECD 2020). By tokenizing underlying assets into digital tokens, which represent a small portion of ownership, smaller-scale investment turns to be financially viable. The fractional ownership of assets would lower investment barriers to attract retail investors to participate in insufficiently divisive and unaffordable assets under the conventional financial system (Worley and Skjellum 2018). Through tokenization, retail investors in EMDEs are not limited to domestic infrastructure investment. They would be granted the opportunity to invest in qualified infrastructure assets in other EMDEs or advanced economies to build a diversified global portfolio. Based on investors' individual needs, they can design and build a bespoke investment portfolio to hedge risks and maximize returns. Fragmentation brought about by tokenization enables retail investors to construct portfolios with well-defined risk exposure and allows for qualified EMDE infrastructure assets to be pursued by investors from all corners of the world.

4.5.2 Community Involvement

Ownership rights of the underlying assets are embedded in digital tokens, such that token holders can participate in decision making by executing their voting rights (Roth et al. 2019). Tokenization opens new access to involve surrounding communities in infrastructure development (Pereira et al. 2019). Free tokens representing the particular right of the infrastructure facility can be distributed to neighboring residents, who are invited as special shareholders. The voice of the surrounding community will be able to influence the planning and future operations of the project. The lack of support from the surrounding community is a substantial risk causing disruptions and delays in construction and operation (Hyland and Bertsch 2018). Tokenization creates a sense of local ownership of the public infrastructure facilities and provides a platform to galvanize social acceptance. If tokens are backed by revenue-generating infrastructure in EMDEs, surrounding residents not only can enjoy the social spillover effects brought by the infrastructure facility but also derive economic benefits as an additional source of income. Tokenization presents a new path to boost the prosperity of EMDE local communities.

> Vignette 4. According to Chang (2020), a hydro-electric power plant along the Belt and Road Initiative (BRI) area is successfully financed through tokenization. The planned construction time of this power plan is more than five years, and the projected cost is about $300 million. Financial analysis indicates the internal rate of return (IRR) of the project is barely over 5%, which is lower than the 10% benchmark for EMDE infrastructure investment. In some cases, the required yields are even higher, hinging on the project and country risks. It is infeasible to get this project built and financed through conventional financial models. In this case of a hydro-electric power plant, $150 million was eventually raised in exchange for tokens worth $300 million, which can be redeemed for future energy consumption. The 50% discount incented businesses and individuals to invest in this project. Through tokenization, core members of the surrounding communities, such as local businesses and residents, who benefits the most from this project, were provided an opportunity to participate and invest in the plant. More importantly, with sufficient funding, this project survived. This green energy plant case illustrates the great potential of how the private sector can be involved through tokenization to facilitate EMDE infrastructure development.

5. CHALLENGES TO TOKENIZATION

5.1 Regulation

The tokenized market needs to comply with the regulations to protect investors, promote stability while facilitating healthy competition (Savelyev 2018). It is not expected to raise issues in jurisdictions since it merely replaces the conventional electronic book-entries system with DLT-enabled networks (OECD 2020). Nevertheless, it is still uncertain which regulatory asset class and reporting structure tokenized assets fall into (Laurent 2018). There are gaps between the novel asset classes and business models created through tokenization and the existing regulatory framework. Unlike some developed counties like Switzerland and the United Kingdom, which have published a series of statements to legislate tokenized assets (crypto asset), EMDEs are moving slowly to regulate the tokenized market (Uzosoki 2019). Some countries, such as China, India, Bolivia, and Ecuador, have banned their citizens or within borders to issue and trade tokenized assets currently (Katten 2019). Regulations in tokenization in EMDEs is inadequate and subject to change. The lack of regulatory clarity for tokenized assets could arise arbitrage opportunities and create an unsecured investment environment, which is considered market risks with a negative impact on long-term investors, thus delaying broader adoption of the tokenized markets (Schwerin 2018). The cross-border transfer is one of the significant tokenization benefits. However, the alignment of both international and domestic regulations fails to support this at this moment. If rules are too stringent, financial efficiency, liquidity, and some of the other benefits brought by tokenization would be undermined. Besides, smart contacts are still not recognized as legal contracts in most jurisdictions and are not legally enforceable unless they have all attributes of traditional contracts (Ryan 2017). These challenges work against the original intent of smart contracts to reduce time and cost. An innovative supervision structure should be designed to prevent diminishing tokenization' compelling value propositions and regulate the tokenized markets.

5.2 Technology

Connections between on-chain tokens and off-chain underlying infrastructure assets are crucial in asset tokenization. A trusted central authority is required to guarantee the connection between the token and the asset, monitor the underlying infrastructure assets, and update status if conditions are changed (OECD 2020). It is unclear which independent entity can be the trusted central party to ensure the connection and build trust among all participates for EMDE infrastructure tokenization. Without the guaranteed connection, it is questionable whether the tokens are actually backed by the underlying infrastructure assets, which would significantly disrupt the credibility of tokenized markets and private sector participation. The blockchain system is considered to be able to offer higher levels of data security. Nevertheless, applications of blockchain could be vulnerable to cyber-attacks (Swan 2015). Actors in tokenized markets have to bear risks like malicious attacks (51% attack) (Sayeed and Marco-Gisbert 2019).

Efficiency gains brought by tokenization can only be realized when a network achieves a sufficient scale (OECD 2020). On the other hand, unless associated benefits are proven and materialized at networks' optimum scale, policymakers and market participants are reluctant to allocate resources to establish a new blockchain-based system to replace the existing system. Hence,

benefit-cost analyses will be important prerequisites prior to the selection of the financing process (Malavolta et al. 2019). The scalability dilemma impedes the development of tokenization at the current stage. It is not guaranteed that coordinated efforts to overcome the scalability challenges can be realized in a short time, but pilot projects (see vignettes) are exploring the potential application modes. How the short-term EMDE infrastructure financing gap can be overcome with blockchain financing remains to be seen.

A lack of available digital infrastructure, or insufficient investment in adequate information and communication technology (ICT) infrastructure are among the biggest barriers faced by EMDEs in adopting blockchain and tokenization (Yu 2016). According to ADB, many developing countries in the region could not provide dynamic and sustainable ICT access to their citizens (ADB 2014). Without stable high-speed internet access, transactions cannot be securely executed on blockchains, which discourages both project sponsors and investors from implementing tokenization. One the other hand, the mining of blocks for blockchain requires significant computational power with edge-computing applications (Imbault et al. 2017). Edge computing is a distributed computing paradigm that brings computation and data storage closer to the location where it is needed, to improve response times and save bandwidth and energy (Zhang and Zheng 2019). Tokenization would place more energy and internet deployment pressures on the already insufficient EMDE energy and ICT infrastructure (Ghosh and Das 2019), though efficiency gains in blockchain energy use are being made.

6. IMPLICATIONS FOR POLICYMAKERS

6.1 Legislation and Regulation

Policymakers in EMDEs need to update the legal system and regulation to ensure new participants, products, services, and risks brought by tokenization are addressed to facilitate coordination and promote stability in a transparent and secure environment. The legal status of asset-backed tokens and smart contracts should be recognized. Asset tokens are aligned for tax purposes. Tax legislation should be modernized to take on board changes raised by tokenized assets (Obrist and Pfister 2019). In conjunction with effective and clear regulations, a feasible plan for adoption published by the national governments would boost the confidence of private sectors to participate in EMDE infrastructure development. Policymakers in EMDEs should also ensure that regulations are not too stringent to hinder infrastructure asset tokenization from flourishing. Indeed, digital financing is already making significant headway in traditionally underbanked communities, and the Gates Foundation is working on digital ‘central bank of the future’ concepts for EMDEs. These advances, as well as the implementation of so-called digital cities, are an encouraging first step towards tokenization and tokenized financing processes for infrastructure.

6.2 Collaboration

Due to the global nature of the blockchain network, standardization is of the essence to promote cross-border transactions and facilitate international cooperation. It is not likely feasible to establish a global standardized legal and regulatory system across jurisdictions in the short run but EDME policymakers, MDBs (e.g., World Bank and ADB), and non-governmental

organizations (NGOs) could initiate a working group to develop a process for test 'low hanging fruit' applications, towards more broadly defined infrastructure investment domains. Policymakers may consider an international collaboration platform to work with the private sector to build transparent and efficient regulatory and monitoring systems, as has been initiated by the UN Department of Economic and Social Affairs (DESA) meetings on implementation of the Climate Accords. Platforms like the Organization for Economic Co-operation and Development (OECD)'s blockchain policy center and World Bank's blockchain lab and should be encouraged to establish knowledge exchange forums. There will be a need for a hybrid globalized governance and reporting system, to integrate target countries' specific tokenization requirements, at the same time seamlessly aligns on a global level built on smart contracts.

6.3 Education

Due to the high-risk nature of EMDE infrastructure investment, governments and international organizations should support and provide an appropriate platform to raise awareness of the value-added characteristics and limitations associated with the innovative technology to educate participants of a future tokenized market. Educational efforts are vital to increase public awareness and enlarge the scalability of the network. Through tokenization, it would be the first time that retail investors worldwide are granted direct investment access to EMDE infrastructure assets. Adequate education and regulation would protect them from unexpected risks and enable them to identify better investment opportunities. EDME governments can work with researchers and industry practitioners to establish an open-access toolbox complied with case studies, lessons learned, and other educational materials, which would facilitate further development and research in this field (OECD 2019). The concept of the toolbox can also be expanded to a global scale with the support of international organizations.

7. CONCLUSION

Infrastructure is essential to alleviate poverty and generate long-term growth in EMDEs. At the same time, existing infrastructure financing models struggle with multiple issues, such as lack of transparency, insufficient efficiency, and limited liquidity. This paper reviews examples of the implementation of asset tokenization in public and private finance of infrastructure in EMDEs. Through tokenization, administrative and financial efficiencies can be improved from the EMDE governments' perspective, including automated auditing, enhanced project monitoring, and lower financing costs. MDBs could initiate coordinated efforts to establish a globally standardized network and benefit from frictionless cross-border transactions, transparent technical advisory, and better financial intervention via tokenization. In terms of private finance, tokenization would elevate the private sector's confidence and enthusiasm via improving infrastructure asset liquidity, opening access to small-scale projects, and enlarging the group of investors to participate in EMDE infrastructure development. Benefits associated with infrastructure asset tokenization are illustrated in Table 3. Four case studies (vignettes) are included in this research to describe the asset tokenization process and illustrate benefits brought by the emerging technology in the context of EMDE infrastructure financing, public finance, and private finance.

Table 3: Summarized Asset Tokenization Benefits

Sources of Financing	Entities	Asset Tokenization Benefits
Public Finance	EMDE Government	Self-enforcing regulation Automated accounting, tax, and auditing Improved public finance efficiency Accountability and transparency in public administration Enhanced data collection
	Multilateral Development Bank	Better monitoring and controlling Incentive to initiate global collaboration Frictionless cross-border transfer Simplified counterparty risks management
Private Finance	Institutional Investors	Secondary trading Access to small-scale projects Reduced financial costs International investment opportunities exposure
	Retail Investors	Enhanced data collection Access to infrastructure investment Lower entry and exit barriers Included in community development Individualized portfolio construction

Sources: Authors

Asset tokenization is still in the early stage of development. It needs to overcome social, regulatory, and technical challenges. Regulation of tokenization in EMDEs is inadequate and in incipient stages of implementation. Smart contacts are still not recognized as legal contracts under most jurisdictions, even in advanced economies. Policymakers in EMDEs need to update the legal system and regulation to facilitate coordination and promote stability in a transparent and secure environment. Cybersecurity and scalability issues should be addressed by the public and private sectors in a coordinated manner. Collaboration and education are considered critical steppingstones to advance tokenization to achieves widespread adoption in EMDEs. EDME policymakers should work with MDBs and the private sector to initiate a working group, set a goal, and start to move steps to achieve it gradually. An open-access toolbox complied with case studies, lessons learned, and other educational materials, which would facilitate further development and international collaboration in this field.

With innovative thinking and bold actions, new waves of financing and novel forms of partnerships would be unlocked from the private sector. Asset tokenization would also play a critical role in revolutionizing public finance for infrastructure to provide efficiency gains to both the public and private sectors. Once the potential risks and barriers for broader applications of tokenization are carefully examined and mitigated, the economy of tokenization will be leveraged to alleviate poverty and accommodate population growth and urbanization in EMDEs. The impact holds a promise to transform both EMDE economies and people's life there.

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