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A Valuation and Collateralization Framework for Tokenized Real-World Assets (RWAs) in Inflationary Economies: Evidence from Industrial Assets in Iran

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ABSTRACT

This study aimed to develop an integrated framework for the valuation, tokenization, and collateralization of industrial real-world assets (RWAs) in inflationary economies, with particular emphasis on enhancing financing capacity, institutional trust, and collateral recognition through blockchain-enabled financial infrastructure. This research employed a conceptual-developmental design and synthesized principles from corporate finance, asset valuation, secured lending, blockchain finance, tokenization, and institutional governance. The proposed framework consists of three interconnected layers: valuation, tokenization, and collateralization. Industrial asset valuation was performed through a hybrid approach combining net asset value (NAV), discounted cash flow (DCF), market-comparable valuation, and useful-life valuation methods. The resulting integrated asset value was transformed into tokenized units through a Special Purpose Vehicle (SPV) structure. Risk-adjusted token pricing incorporated industrial, liquidity, and legal-operational risk factors, while institutional credibility was measured using a Composite Institutional Trust Index (CITI). The framework further included collateral haircuts, maximum advance rates, collateral coverage monitoring, scenario analysis, and sensitivity testing. An illustrative case involving an Iranian manufacturing production line was used to demonstrate practical implementation. The framework demonstrated that industrial assets can be converted into transparent and collateralizable digital claims while maintaining productive operation. Under the illustrative case assumptions, the hybrid valuation model generated an integrated asset value of approximately USD 52.65 million. After applying aggregate risk adjustments, trust calibration, collateral haircuts, and lending constraints, 500,000 pledged tokens supported an estimated financing capacity of approximately USD 2.01 million. Scenario analyses revealed substantial sensitivity to liquidity conditions, risk loadings, governance quality, inflation, and foreign-exchange shocks. Results further indicated that institutional trust enhances collateral acceptance but should remain bounded to prevent governance factors from overshadowing underlying financial fundamentals. The proposed framework offers a comprehensive architecture that integrates valuation discipline, digital tokenization, institutional trust generation, and prudent collateral engineering for productive industrial assets. The model demonstrates how tokenized RWAs can facilitate access to financing in inflationary and financially constrained economies while maintaining conservative risk management standards. The framework provides a practical foundation for future pilot programs, regulatory sandboxes, banking applications, and Islamic finance implementations involving industrial asset tokenization.

Keywords: Real-World Asset Tokenization; Industrial Assets; Asset Valuation; Digital Collateral; Collateralization; Institutional Trust; Self-Generating Trust

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Introduction

The tokenization of real-world assets (RWAs) has emerged as one of the most consequential developments in digital finance because it connects blockchain-based representation with legally and economically identifiable claims on tangible or financial assets. The intellectual origins of this transformation can be traced to the original design of decentralized peer-to-peer value transfer, in which distributed ledgers made it possible to record transactions without relying entirely on a centralized intermediary (1). Subsequent developments in cryptocurrency technologies, cryptographic verification, consensus mechanisms, and programmable ledgers expanded this idea from digital cash toward broader financial and contractual applications (2). Blockchain's economic importance lies not only in technological novelty, but also in its capacity to reduce verification costs, improve settlement transparency, and create programmable forms of ownership, transfer, and compliance (3). Within this context, tokenization can be understood as the conversion of rights, claims, or economic interests into digital tokens recorded on a programmable infrastructure. However, the value of tokenization depends on whether the token is connected to enforceable rights, credible valuation, reliable custody, and transparent governance.

The growing literature on decentralized finance and blockchain-based financial markets shows that tokenization is part of a broader movement toward programmable financial infrastructure. Decentralized finance has introduced smart-contract-based lending, trading, liquidity provision, and asset management, demonstrating that financial functions can be redesigned through automated protocols (4, 5). At the same time, this literature warns that automation does not eliminate financial risk, legal uncertainty, operational fragility, or governance problems (6). DeFi systems may appear decentralized at the interface level, but risks are frequently concentrated in protocol governance, collateral design, oracle systems, and liquidity mechanisms (7). Therefore, tokenization should not be treated as a purely technological process. It is better understood as a financial-institutional arrangement in which programmable assets require legal enforceability, valuation discipline, collateral controls, and trust-generating governance mechanisms.

A central issue in tokenized finance is valuation. Tokenized assets may become tradable and divisible, but divisibility does not create fundamental value unless the underlying asset has measurable economic worth. Financial valuation theory emphasizes that asset value must be derived from expected cash flows, replacement cost, market comparables, risk, uncertainty, and the quality of available information (8). This issue becomes more complex when assets are illiquid, distressed, highly specialized, or exposed to macroeconomic volatility, because valuation must incorporate both measurable fundamentals and substantial uncertainty (9). Tokenization can improve recordkeeping and transferability, but it cannot resolve weak cash-flow evidence, unreliable appraisals, unclear title, or market illiquidity. Therefore, any credible RWA framework requires a hybrid valuation architecture that combines asset-based, income-based, market-based, and useful-life approaches while explicitly recognizing uncertainty.

Collateral is another major foundation of RWA tokenization. Financial theory shows that collateral values shape borrowing capacity, credit cycles, liquidity, and crisis dynamics. When collateral quality deteriorates or market participants lose confidence in asset values, funding conditions can tighten rapidly (10). Market liquidity and funding liquidity are mutually reinforcing, meaning that illiquid collateral can reduce funding capacity precisely when firms most need financing (11). Shadow-banking research similarly shows how securitized and collateralized claims may expand credit when confidence is high, but can create fragility when asset quality, transparency, or governance are weak (12). These insights are directly relevant to tokenized industrial RWAs because the token may improve the technical transfer of claims, but lenders will recognize collateral value only if the asset can be valued, monitored, pledged, and enforced under credible legal and institutional conditions.

The development of tokenized assets also raises questions about trust and legal architecture. Blockchain has often been described as a technology that substitutes institutional trust with cryptographic proof, but in real-world asset markets this substitution is incomplete. Physical assets remain off-chain, and their condition, ownership, insurance, maintenance history, encumbrances, and cash-flow performance must be verified through institutions, auditors, custodians, courts, registries, and data providers. The governance literature on blockchain emphasizes that transparency and distributed records can strengthen corporate governance, but they do not eliminate the need for legal accountability and institutional oversight (13). Similarly, blockchain may create a new architecture of trust, but such trust is produced through the interaction of code, law, organizations, and social acceptance (14). Legal scholarship further shows that capital is created through legal coding, meaning that asset value depends heavily on enforceable rights, priority rules, collateral recognition, and institutional recognition (15). For this reason, tokenized RWAs must be embedded in a legal structure that defines the relationship among the asset, token, issuer, investor, custodian, lender, and enforcement mechanism.

Smart contracts are central to tokenized asset systems because they can automate transfers, compliance rules, payment waterfalls, margin alerts, and collateral controls. However, smart contracts must be connected to legal documents and real-world obligations. The concept of smart contract templates shows the importance of linking executable code with legal prose, operational parameters, and contractual enforceability (16). This is especially important for industrial assets, where the token does not simply represent a digital-native asset, but rather a claim on physical machinery, production lines, facilities, or usufruct rights. In such contexts, code may automate registry actions, but it cannot by itself resolve title disputes, enforce insolvency priority, verify machine condition, or determine maintenance compliance. Therefore, the proposed framework treats smart contracts as part of a broader collateral architecture rather than as a substitute for valuation, legal structuring, or institutional governance.

Recent studies on tokenization have expanded the field from crypto-assets to broader real-world and financial assets. Tokenomics research has shown that token value depends on adoption dynamics, network effects, design incentives, and valuation mechanisms (17). The Internet-of-Value perspective further suggests that tokenization can enable new forms of value exchange by integrating digital infrastructure, process automation, and verifiable asset representation (18). Empirical and applied studies have examined tokenized assets across decentralized settings, highlighting the balance between efficiency, value creation, and risk distribution (19). Other recent work has emphasized technical scalability and security for RWA tokenization through Ethereum staking and layer-2 solutions, showing that infrastructure design remains crucial for large-scale implementation (20). Nevertheless, much of this literature remains concentrated on general RWA systems, financial assets, real estate, bonds, or digital infrastructure rather than productive industrial assets.

The empirical literature on specific tokenized asset classes also reveals important but incomplete lessons for industrial RWAs. Real estate tokenization research shows that fractional ownership, reduced entry barriers, improved liquidity, and more flexible property investment structures can transform traditionally illiquid asset markets (21). Government bond tokenization illustrates how standardized financial instruments can benefit from tokenized settlement, collateral mobility, and market-infrastructure improvements (22). Empirical evidence on tokenized bonds further suggests that tokenization may reduce trading-process costs and environmental costs in some financial-market contexts (23). However, these asset classes differ significantly from industrial production lines, specialized machinery, logistics equipment, and operating facilities. Industrial assets are heterogeneous, maintenance-sensitive, technologically specific, dependent on utilization, exposed to operational downtime, and often difficult to liquidate without disrupting production. Therefore, their tokenization requires a more conservative valuation and collateralization model than the models commonly applied to standardized securities or real estate.

Fintech and digital financial transformation have also shown that tokenized and programmable finance may reshape banking, capital markets, and monetary infrastructures (24). Embedded supervision has been proposed as a way to integrate regulatory oversight directly into digital financial systems through automated data access, programmable compliance, and transparent transaction monitoring (25). These ideas are highly relevant to tokenized RWAs because lenders and regulators require continuous visibility into collateral status, ownership, transfer restrictions, and risk metrics. Yet embedded supervision requires reliable data feeds and credible institutional design. In industrial RWA markets, the oracle problem is particularly acute because blockchain systems must depend on off-chain information about asset condition, production performance, insurance coverage, maintenance status, and legal encumbrances. Without reliable oracles and periodic independent verification, tokenized collateral may create false precision rather than genuine transparency.

The need for a disciplined framework is especially strong in inflationary economies. In such environments, replacement costs may rise rapidly, currency depreciation may distort local-currency valuation, and long-term financing may become constrained. Firms may hold valuable productive assets while remaining unable to mobilize those assets efficiently as collateral. Inflation can increase nominal asset values, but it can also increase discount rates, operating costs, liquidity premia, and foreign-exchange risk. Therefore, a valuation model for tokenized industrial RWAs must distinguish between local-currency and hard-currency cash flows, separate operating cash flows from terminal residual value, and incorporate country risk, liquidity risk, and FX risk in the discount rate. A simple replacement-cost model may overstate collateral capacity if operating margins deteriorate, while a simple DCF model may understate asset-based value when inflation raises replacement costs. This creates a need for an integrated, inflation-aware hybrid valuation method.

Islamic finance provides another important perspective for asset-backed tokenization in jurisdictions where Shariah-compatible structures are relevant. Asset recycling and Islamic finance frameworks emphasize the productive use of tangible assets, usufruct, lease-based structures, and asset-backed financing rather than purely interest-bearing claims (26). Industrial RWA tokenization may be compatible with such principles if tokens represent ownership interests, usufruct rights, lease receivables, or clearly defined beneficial interests in tangible productive assets. A Special Purpose Vehicle can hold the relevant asset rights, issue tokens representing proportional claims, lease the asset back to the operating firm, and distribute lease-linked returns according to contractual rules. However, Shariah compatibility cannot be assumed automatically; it requires asset backing, risk allocation, clear maintenance responsibilities, and review of repurchase undertakings and return structures.

Despite these advances, several gaps remain in the literature. First, industrial assets are underrepresented relative to real estate, bonds, financial securities, commodities, and generic RWAs. Second, many studies discuss tokenization benefits without integrating valuation, legal structure, risk adjustment, institutional trust, and collateral recognition into a single operational model. Third, existing approaches rarely provide a reproducible framework for inflationary economies, where inflation, FX depreciation, convertibility risk, and replacement-cost volatility directly affect valuation and lending capacity. Fourth, institutional trust is often discussed qualitatively rather than translated into measurable components such as smart-contract assurance, regulatory status, custodian quality, SPV transparency, and disclosure reliability. Fifth, collateral capacity is often not linked to conservative haircuts, maximum advance rates, realized loan-to-value ratios, and collateral coverage triggers. These gaps limit the practical usefulness of RWA tokenization for banks, regulators, industrial firms, and investors in emerging and financially constrained economies.

Accordingly, the present study develops an integrated valuation and collateralization framework for tokenized industrial RWAs in inflationary economies by combining hybrid asset valuation, SPV-based token issuance, risk-adjusted token pricing, a Composite Institutional Trust Index, collateral haircuts, maximum advance rates, and dynamic collateral coverage monitoring into a single reproducible architecture.

Methods and Materials

This study employed a conceptual-developmental research design aimed at constructing an integrated framework for the valuation, tokenization, and collateralization of industrial real-world assets (RWAs) in inflationary economies. Because deep and mature secondary markets for tokenized industrial assets do not yet exist in Iran and comparable emerging economies, the study did not rely on traditional empirical sampling, surveys, or experimental observations. Instead, it developed a theoretically grounded and operationally reproducible framework by synthesizing principles from corporate finance, asset valuation, secured lending, asset-backed finance, blockchain-based tokenization, governance theory, and institutional trust literature. The research process followed a sequential architecture consisting of asset identification and eligibility assessment, valuation modeling, token issuance design, risk-adjusted token pricing, trust calibration, collateralization modeling, and collateral monitoring mechanisms. The framework was designed to permit future implementation using audited project-level data and regulated financial infrastructure. An illustrative case involving a manufacturing production line in Iran was incorporated to demonstrate the practical application of the proposed model. The industrial asset selected for illustration represented a productive manufacturing facility operating within an inflationary and foreign-exchange-constrained environment. Asset eligibility was determined according to predefined criteria including legal ownership clarity, identifiable location, measurable economic utility, availability of technical documentation, insurance coverage, independent appraisal feasibility, and legal suitability for transfer into a bankruptcy-remote Special Purpose Vehicle (SPV) structure. Assets characterized by disputed ownership, significant environmental liabilities, severe operational deficiencies, or substantial legal uncertainties were considered unsuitable for tokenization or subject to enhanced collateral haircuts and risk adjustments.

The framework relied on a structured data architecture integrating financial, operational, legal, governance, and market-related information. At the issuance stage, the required data included independent appraisal reports, ownership and title documents, insurance policies, maintenance histories, production records, environmental permits, asset photographs, serial-number documentation, and records of existing liens or encumbrances. During the operational stage, additional information streams included periodic appraisal updates, asset-condition inspections, maintenance logs, enterprise resource planning (ERP) production metrics, utilization data obtained from Internet-of-Things (IoT) systems where available, insurance-status reports, regulatory filings, custodian attestations, and secondary-market liquidity indicators. Data governance procedures required validation of all inputs through an independent calculation agent or oversight committee before incorporation into valuation updates, token repricing, collateral monitoring, or margin-call determinations.

The principal valuation variables included gross asset value (Vg), representing the appraised replacement or current value of the industrial asset prior to deductions; net asset value (V_NAV), representing asset value after liabilities and reserves; discounted cash flow value (V_DCF), representing the present value of future operating cash flows and terminal residual value; market value (V_MKT), derived from comparable asset transactions; useful-life value (V_UL), reflecting depreciation-adjusted economic value; and integrated asset value (VA), representing the weighted combination of all valuation approaches. Tokenization variables included the total number of issued tokens (N), pledged token quantity (Q), base token price (P_base), risk-adjusted token price (P_risk), and final governance-adjusted token price (P_final). Risk assessment variables comprised industrial risk (α), liquidity risk (β), legal-operational risk (γ), and aggregate risk loading (ρ). Institutional trust variables included the Composite Institutional Trust Index (CITI) and the bounded trust-adjustment factor (τ), which captured the influence of governance quality, disclosure reliability, regulatory status, custodian quality, and smart-contract assurance on token acceptance. Collateralization variables consisted of collateral haircut (HC), haircut weighting factors (φi), normalized risk scores (Ri), effective collateral value (ECV), maximum advance rate (MAR), realized loan-to-value ratio (LTV_realized), maximum financing capacity (Loan_max), and collateral coverage ratio (CCR). Collectively, these variables formed an integrated valuation-to-collateralization architecture capable of linking industrial asset performance, institutional trust, and lending capacity within a single analytical framework.

Data analysis was conducted through a multi-stage modeling process that integrated valuation, tokenization, risk adjustment, trust generation, and collateralization mechanisms. The valuation stage employed four complementary approaches: net asset value analysis, discounted cash flow analysis, market-comparable valuation, and useful-life valuation. These methods were combined using predetermined weighting procedures to generate an integrated asset value. The weighting structure was designed to reflect the relative reliability of available evidence, considering factors such as asset age, replacement cost, market comparability, operational cash-flow stability, and data quality. Following valuation, the integrated asset value was converted into a base token price through division by the total token supply. Risk-adjusted token prices were then estimated by applying calibrated deductions for industrial, liquidity, and legal-operational risks.

Institutional trust was subsequently incorporated through the Composite Institutional Trust Index, which quantified governance quality using indicators related to smart-contract assurance, regulatory recognition, custodial arrangements, SPV transparency, and disclosure practices. The resulting trust adjustment was intentionally bounded to ensure that governance quality enhanced collateral acceptance without overwhelming underlying financial fundamentals. In the collateralization phase, effective collateral values were calculated after application of risk-adjusted token pricing and collateral haircuts. Lending capacity was then determined through maximum advance rate constraints, while realized loan-to-value ratios and collateral coverage ratios were calculated to assess collateral adequacy and risk exposure. To evaluate framework robustness, scenario analyses and one-way sensitivity analyses were conducted. These analyses examined the effects of variations in discount rates, inflation conditions, exchange-rate shocks, risk loadings, trust levels, collateral haircuts, and advance-rate policies on asset valuation and financing capacity. Continuous monitoring mechanisms were incorporated through collateral coverage thresholds and operational trigger zones, allowing updated market conditions, governance events, appraisal revisions, and asset-performance data to feed back into the valuation and collateralization process. This recursive analytical structure ensured that the framework remained responsive to changing economic conditions and evolving risk profiles while maintaining transparency, reproducibility, and prudential conservatism.

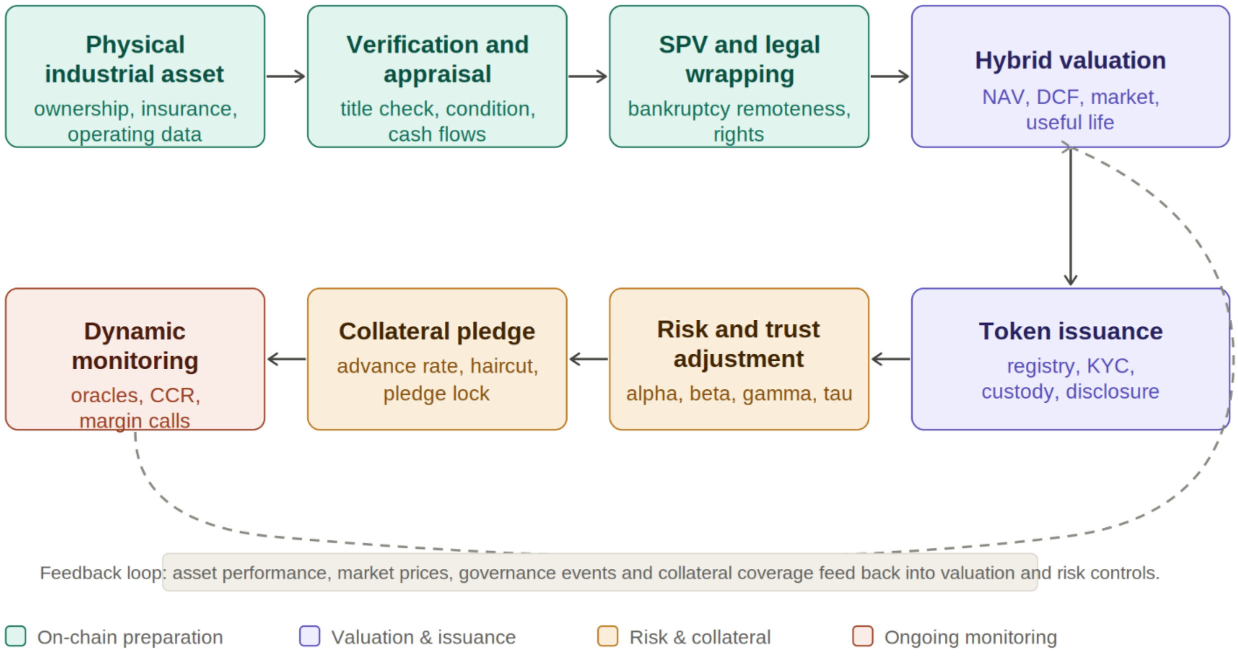

Figure 1. Integrated industrial RWA tokenization framework

Findings and Results

The findings of the study are presented as an integrated valuation-to-collateralization framework for tokenized industrial real-world assets (RWAs) in inflationary economies. The framework shows that the economic usefulness of tokenization depends on a sequence of linked analytical steps: estimating the value of the underlying productive asset, converting that value into token units, adjusting token prices for industrial, liquidity, and legal-operational risks, incorporating a bounded institutional trust adjustment, applying collateral haircuts, determining maximum lending capacity, and monitoring collateral coverage over time. The numerical illustration demonstrates that tokenization does not automatically unlock the full value of an industrial asset; rather, the bankable collateral value is materially reduced by risk, legal enforceability, market liquidity, governance quality, and advance-rate limits. The findings are based on the valuation, token pricing, collateralization, scenario, sensitivity, regulatory, and future-research framework developed in the uploaded study.

The first analytical layer of the framework was the valuation model. Net asset value provided a conservative floor by deducting asset-linked liabilities and risk reserves from the gross appraised value. Discounted cash flow valuation captured the productive capacity of the industrial asset by estimating operating cash flows separately from terminal residual value. Market valuation introduced comparable-asset evidence, while useful-life valuation incorporated the depreciation pattern and remaining economic life of the asset. The integrated asset value was then calculated as a weighted combination of these four valuation outputs.

Table 1. Valuation equations and analytical role

Valuation component	Formula	Analytical interpretation
Net asset value	$V_{NAV} = V_g - L - RR$	Provides a conservative asset-based floor by deducting asset-linked debt, liens, and risk reserves from gross appraised value.
Inflation- and FX-adjusted DCF value	$V_{DCF} = \sum_{t=1}^{n} \frac{OCF_t}{(1+r_n)^t} + \frac{RV_n}{(1+r_n)^n}$	Estimates the present value of operating cash flows and terminal residual value over the remaining economic life of the asset.
Nominal discount rate	$r_n = [(1+r_{real})(1+\pi_e)(1+CRP)(1+LP)(1+FXP)] - 1$	Incorporates real return, expected inflation, country-risk premium, liquidity premium, and foreign-exchange risk premium.
Approximate discount rate	$r_n \approx r_{real} + \pi_e + CRP + LP + FXP$	Can be used only when values are small; the multiplicative form is preferred in high-inflation settings.
USD operating cash flow conversion	$OCF_t^{USD} = \frac{Revenue_t^{LCU} - Cost_t^{LCU}}{S_t}$	Converts local-currency operating cash flow into hard-currency terms using the expected local-currency price of one unit of hard currency.
Market value	$V_{MKT} = P_c \times A_{adj}$	Uses comparable transaction prices adjusted for age, capacity, location, technology, maintenance condition, utilization, regulation, and exchange-rate conditions.
Useful-life value	$V_{UL} = IV \times max[0, (1 - T/L)^{\kappa}]$	Estimates remaining economic value from initial value, elapsed time, expected life, and depreciation pattern.
Integrated asset value	$V_A = \omega_{NAV}V_{NAV} + \omega_{DCF}V_{DCF} + \omega_{MKT}V_{MKT} + \omega_{UL}V_{UL}$	Combines the four valuation approaches into the asset value used for token issuance.
Weight constraint	$\omega_{NAV} + \omega_{DCF} + \omega_{MKT} + \omega_{UL} = 1;\ \omega_i \geq 0$	Ensures that the integrated valuation weights are non-negative and sum to one.

The weighting process was not treated as arbitrary. First, preliminary weights were assigned according to the reliability of available valuation evidence and the economic characteristics of the asset. Second, these weights were recommended for validation through the Analytic Hierarchy Process, Delphi elicitation, or a documented credit-committee scoring procedure. AHP is appropriate when experts can compare the relative reliability of NAV, DCF, market, and useful-life evidence, whereas Delphi elicitation is useful when financial, technical, and legal experts must converge on valuation assumptions in the absence of deep comparable markets.

Table 2. Weighting logic and illustrative valuation weights

Evidence condition or asset type	NAV weight	DCF weight	Market weight	Useful-life weight	Recommended implication
Audited operating history and stable capacity utilization	—	Increase	—	—	Income evidence is reliable, so greater emphasis should be placed on DCF valuation.
Recent comparable transactions for similar equipment	—	—	Increase	—	Observable market evidence justifies greater market-value weighting.
Specialized asset with limited resale market	Increase	Increase	Reduce	—	Market comparables are less reliable, so NAV and income evidence become more important.
High inflation and rapidly changing replacement cost	Increase	—	—	—	NAV should receive more attention, and V_g should reflect current replacement cost.
Older asset with uncertain maintenance condition	—	—	—	Increase	Useful-life valuation and technical due-diligence reserves become more important.
Limited financial statements or weak audit trail	Increase	Reduce	—	—	Conservative asset-based measures should be prioritized over DCF estimates.
Manufacturing production line	30%	35%	20%	15%	Balanced structure; operating cash flows matter, but resale and condition uncertainty remain material.
Power-generation facility	20%	50%	15%	15%	Cash-flow evidence dominates when offtake, fuel, and output data are reliable.
Industrial warehouse	40%	20%	30%	10%	Asset and comparable-market evidence are often stronger than operating cash-flow attribution.
Specialized imported machinery	35%	30%	10%	25%	Useful life and replacement cost dominate where resale-market evidence is weak.

After integrated asset value was estimated, the model converted asset value into a base token price by dividing the integrated asset value by the number of issued tokens. Risk calibration then adjusted the token price downward according to industrial risk, liquidity risk, and legal-operational risk. These parameters were designed to be calibrated rather than assumed. Each was expressed as a percentage deduction from base token price using normalized risk scores and maximum risk loadings.

Table 3. Token pricing, risk calibration, and institutional trust equations

Analytical stage	Formula	Interpretation
Base token price	$P_{base} = V_A/N$	Converts integrated asset value into a token price based on the number of tokens issued by the SPV.
Risk-parameter calibration	$\alpha = \alpha_{max} \times S_{ind};\ \beta = \beta_{max} \times S_{liq};\ \gamma = \gamma_{max} \times S_{leg}$	Calibrates industrial risk, liquidity risk, and legal-operational risk using normalized scores.
Total risk loading	$\rho = \alpha + \beta + \gamma$	Aggregates token price risk deductions.
Risk-adjusted token price	$P_{risk} = P_{base} \times max[0, (1 - \rho)]$	Produces the conservative token price used for collateral analysis.
Trust adjustment	$\tau = \tau_{max} \times CITI,\ 0 \leq \tau_{max} \leq 0.10,\ 0 \leq CITI \leq 1$	Applies a bounded governance premium that cannot exceed 10% of the risk-adjusted price.
Composite Institutional Trust Index	$CITI = \lambda_1 S_{audit} + \lambda_2 S_{reg} + \lambda_3 S_{custody} + \lambda_4 S_{SPV} + \lambda_5 S_{disclosure}$	Measures institutional trust through audit, regulation, custody, SPV transparency, and disclosure reliability.
CITI weight constraint	$\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 = 1;\ \lambda_i \geq 0$	Ensures that CITI weights are non-negative and sum to one.
Final token price	$P_{final} = P_{risk} \times (1 + \tau)$	Produces the final governance-adjusted token price.

The risk calibration rubric distinguished low, moderate, and high risk conditions for each parameter. Industrial risk was low when the asset had high utilization, strong maintenance, standard technology, and insurance coverage; it was moderate when downtime, maintenance uncertainty, or sector cyclicality were present; and it was high when the asset was obsolete, custom-built, poorly maintained, exposed to downtime, or environmentally risky. Liquidity risk was low when a permissioned secondary market, market makers, and a broad eligible investor base existed; moderate when transfers were limited or auction-based; and high when there was no secondary market, severe transfer restriction, or uncertain buyer demand. Legal-operational risk was low when SPV rights, contracts, pledge enforceability, and custody were clear; moderate when enforceability or registry uncertainty existed; and high when title, pledge law, token-holder priority, or custody were weak. Possible proxies included maintenance backlog, utilization, downtime, bid-ask spreads, trading frequency, investor concentration, legal opinions, registry checks, custodian ratings, court enforceability, and AML/KYC findings.

The Composite Institutional Trust Index was introduced to measure whether the off-chain institutions supporting the token were strong enough to enhance financial acceptance. The five CITI components were smart-contract assurance, regulatory or sandbox status, custodian quality, SPV transparency, and ongoing disclosure reliability. Smart-contract assurance addressed code and execution risk; regulatory status addressed legal perimeter and compliance risk; custodian quality addressed safekeeping, segregation, and key management; SPV transparency addressed bankruptcy remoteness, asset segregation, and token-holder rights; and disclosure reliability addressed the oracle problem by requiring appraisals, maintenance information, insurance status, and collateral reports to remain updated and auditable. Suggested initial weights were 20% for each component, although the framework allowed future recalibration through AHP, Delphi elicitation, credit-committee scoring, or regression against observed spreads, haircuts, liquidity, and default outcomes.

Table 4. Composite Institutional Trust Index scoring

CITI component	Score 0	Score 0.5	Score 1.0
S_{audit}: smart-contract assurance	No independent audit or unresolved critical findings.	Independent audit with minor findings and remediation plan.	Independent audit, formal verification where feasible, and public remediation report.
S_{reg}: regulatory status	No legal opinion, no licensing, or high unresolved regulatory risk.	Legal opinion and pilot or sandbox engagement.	Licensed or formally approved platform with continuing reporting obligations.
$S_{custody}$: custodian quality	Self-custody only or weak key controls.	Qualified custodian or multi-signature controls with audit.	Regulated custodian, segregation, insurance, and recovery procedures.
S_{SPV}: SPV transparency	Unclear rights, weak asset segregation, or no bankruptcy-remoteness analysis.	Basic SPV documentation and annual reporting.	Bankruptcy-remoteness opinion, audited SPV accounts, and clear token-holder rights.
$S_{disclosure}$: ongoing reporting	No standardized reporting.	Quarterly asset and collateral reports.	Near-real-time dashboards plus audited periodic reports and data hashes.

The bounded trust premium was a prudential design feature. It did not imply that trust has a universal market price. Instead, the 10% ceiling reflected the principle that governance quality can improve collateral acceptance and reduce information frictions, but it should not dominate observable asset value, cash-flow capacity, or liquidation risk. Weak governance did not generate a negative trust premium; instead, severe governance weakness was captured through higher legal-operational risk, a larger governance component in the haircut model, or exclusion from collateral eligibility.

The collateralization model translated token value into lender-recognized collateral value. Haircuts were used to incorporate valuation uncertainty, liquidity constraints, market risk, and governance risk. The model deliberately distinguished the maximum advance rate from the realized loan-to-value ratio. Maximum advance rate was treated as an exogenous lender-set policy ceiling, while realized LTV was calculated after loan origination.

Table 5. Collateralization equations, risk zones, and operational triggers

Component	Formula or threshold	Interpretation
Haircut	$HC = HC_{min} + (HC_{max} - HC_{min}) \times (\phi_A R_A + \phi_L R_L + \phi_M R_M + \phi_G R_G)$	Converts asset risk, liquidity risk, market risk, and governance risk into a collateral haircut.
Haircut constraint	$\phi_A + \phi_L + \phi_M + \phi_G = 1;\ 0 \le R_i \le 1$	Ensures that haircut weights sum to one and normalized risk scores remain between zero and one.
Effective collateral value	$ECV = P_{final} \times Q \times (1 - HC)$	Calculates lender-recognized collateral value after applying the final token price, pledged token quantity, and haircut.
Maximum loan	$Loan_{max} = ECV \times MAR$	Estimates maximum financing capacity under the lender-set maximum advance rate.
Realized loan-to-value	$LTV_{realized} = \frac{Outstanding\ Loan}{ECV} \le MAR$	Measures actual loan exposure relative to effective collateral value.
Collateral coverage ratio	$CCR = \frac{ECV}{Outstanding\ Loan}$	Measures collateral adequacy over time.
Low-risk haircut	10–20%	Appropriate for audited assets with strong legal claims and reliable market or cash-flow evidence.
Moderate-risk haircut	20–35%	Appropriate for acceptable assets with limited secondary liquidity or some legal uncertainty.
High-risk haircut	35–50%	Appropriate for specialized, illiquid, or governance-sensitive assets.
Very high-risk haircut	Above 50% or ineligible	Applies where enforceability is unclear, liquidity is severely constrained, or ownership is disputed.
Low-risk MAR ceiling	70%	Suitable where legal claim, liquidity, valuation audit, and cash-flow stability are strong.
Moderate-risk MAR ceiling	60%	Suitable for early bank pilots with moderate liquidity and reliable governance.
High-risk MAR ceiling	40%	Suitable for specialized or illiquid assets with elevated stress risk.

Experimental-asset MAR ceiling	20–30%	Suitable for new platforms, weak trading data, or limited enforceability history.
Safe CCR zone	Above 150%	Routine reporting only; pledged tokens remain locked by the custodian.
Warning CCR zone	120–150%	Borrower receives notice and may voluntarily post collateral.
Critical CCR zone	Below 120%	Additional collateral, partial repayment, or controlled liquidation becomes mandatory.
Default zone	Below negotiated cure level or missed cure deadline	Pledge enforcement, token transfer to lender, or sale through a permitted market is triggered.

The collateral coverage ratio should be monitored by a calculation agent, custodian, or regulated platform. In early-stage industrial RWA systems, daily automated monitoring may be unnecessary when asset values update monthly or quarterly; however, token prices, legal events, insurance status, and other enforceability-related variables should be monitored more frequently. Smart contracts may lock pledged tokens and emit alerts, but enforcement must remain linked to legally binding pledge documents and custodian procedures.

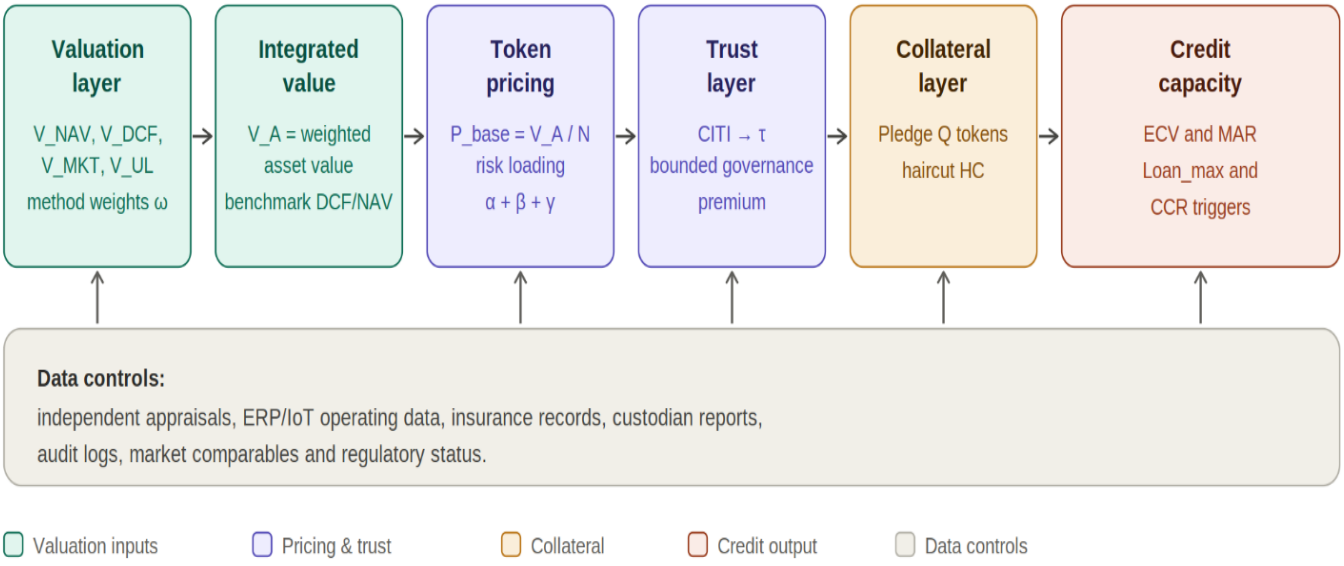

Figure 2. Valuation-to-collateralization pipeline

Figure 2 summarizes the pipeline through which valuation outputs feed into token pricing, risk adjustment, trust calibration, haircut application, advance-rate determination, and collateral coverage monitoring. The model is recursive because new appraisals, market conditions, governance events, operating data, and legal developments can feed back into token prices and collateral coverage ratios.

The numerical case study was illustrative and publicly benchmarked. It was not presented as confidential firm-level evidence, a market back-test, or proof that industrial RWA tokens already trade in Iran at the values shown. Iran was used because inflation, currency depreciation, sanctions-related constraints, banking-sector limitations, and limited long-term external finance make collateral mobilization especially important. The case used USD-denominated valuation to avoid mixing local-currency inflation with hard-currency asset finance. Therefore, the 15% discount rate was interpreted as a hard-currency industrial asset rate that included country, liquidity, and FX convertibility risk rather than a local-currency nominal rate.

Table 6. Case-study assumptions and valuation-tokenization outputs

Item	Base value or output	Interpretation
Asset type	Manufacturing production line	Productive industrial asset kept in operation.
Current replacement cost, $\boldsymbol{V_g}$	USD 70 million	Assumed hard-currency replacement benchmark.
Outstanding asset-linked debt, $\boldsymbol{L}$	USD 12 million	Debt or liens attached to the asset or originator claim.
Risk reserve, $\boldsymbol{RR}$	USD 3 million	Reserve for maintenance, legal, and operating uncertainty.
Annual operating cash flow, $\boldsymbol{OCF}$	USD 8 million	Net operating cash flow before token financing.
Remaining useful life, $\boldsymbol{n}$	14 years	Economic life used in DCF.
Residual value, $\boldsymbol{RV_n}$	USD 10 million	Expected terminal value excluding operating cash flow.
Discount rate, $\boldsymbol{r_n}$	15%	Hard-currency nominal rate including risk premia.
Number of tokens, $\boldsymbol{N}$	5,265,000	Chosen so the rounded base token price equals USD 10.
Pledged tokens, $\boldsymbol{Q}$	500,000	Tokens locked as collateral for the loan.
NAV	USD 55.00 million	$70 - 12 - 3 = 55$; conservative asset-based benchmark.
DCF	USD 48.00 million	Captures operating cash-flow value but is sensitive to discount rate and forecast quality.
Market value	USD 60.00 million	Provides external comparable benchmark, although comparables may be sparse.
Useful-life value	USD 49.00 million	Reflects remaining economic life and depreciation assumptions.
Hybrid integrated value, $\boldsymbol{V_A}$	USD 52.65 million	$V_A = 0.30(55) + 0.35(48) + 0.20(60) + 0.15(49) = USD\ 52.65\ million.$
Base token price	USD 10.00	$P_{base} = 52{,}650{,}000/5{,}265{,}000 = USD\ 10.00.$
Industrial risk, $\boldsymbol{\alpha}$	5%	Standard manufacturing line with moderate sector and maintenance risk.
Liquidity risk, $\boldsymbol{\beta}$	7%	Permissioned secondary market assumed, but early-stage liquidity remains limited.
Legal-operational risk, $\boldsymbol{\gamma}$	3%	SPV and pledge documentation assumed, but enforceability precedent remains limited.
Total risk loading, $\boldsymbol{\rho}$	15%	$\rho = \alpha + \beta + \gamma.$
Risk-adjusted token price	USD 8.50	$P_{risk} = 10.00 \times (1 - 0.15) = USD\ 8.50.$
CITI score	0.50	Indicates a partially developed trust layer.
Trust factor, $\boldsymbol{\tau}$	5%	$\tau = 0.10 \times 0.50 = 0.05.$
Final token price	USD 8.93	$P_{final} = 8.50 \times (1 + 0.05) = USD\ 8.93.$
Haircut, $\boldsymbol{HC}$	25%	Moderate collateral conservatism.
Effective collateral value, $\boldsymbol{ECV}$	USD 3.35 million	$ECV = 8.93 \times 500{,}000 \times (1 - 0.25) = USD\ 3.35\ million.$
Maximum advance rate, $\boldsymbol{MAR}$	60%	Early bank-pilot lending ceiling.
Maximum financing capacity	USD 2.01 million	$Loan_{max} = 3.35 \times 0.60 = USD\ 2.01\ million.$

The case findings show that an industrial asset with an integrated value of USD 52.65 million supported only USD 2.01 million of immediate collateralized financing when a limited token pledge, aggregate risk adjustment, bounded trust premium, haircut, and maximum advance rate were applied. This result is central to the framework because it demonstrates that tokenized industrial collateral should be treated conservatively, particularly in early-stage markets where legal enforceability, secondary-market liquidity, and institutional trust are still developing.

The scenario analysis varied base token price, aggregate risk loading, and trust adjustment while holding pledged tokens at 500,000, haircut at 25%, and maximum advance rate at 60%. The analysis was not a statistical sensitivity test; rather, it was a structured scenario exercise with disclosed assumptions. The one-way sensitivity analysis then changed one driver at a time while keeping the other base assumptions constant.

Table 7. Scenario and one-way sensitivity findings

Analysis type	Scenario or driver	Favorable or optimistic value	Base value	Adverse or pessimistic value	Interpretation
Scenario input	Base token price	USD 10.75	USD 10.00	USD 9.20	Scenario valuation changes directly affect final token price.
Scenario input	Aggregate risk loading, ρ	12%	15%	25%	Higher risk loading reduces the collateral-recognized token price.
Scenario input	Trust factor, τ	8%	5%	3%	Trust improves final token price, but remains bounded.
Scenario calculation	Final token price	$10.75 \times 0.88 \times 1.08$ $= USD\ 10.22$ $\approx USD\ 10.20$	10.00×0.85 $\times 1.05$ $= USD\ 8.93$	$9.20 \times 0.75 \times 1.03$ $= USD\ 7.11$ $\approx USD\ 7.10$	Final token price reflects valuation, risk deduction, and trust adjustment.
Scenario output	Effective collateral value	USD 3.83 million	USD 3.35 million	USD 2.66 million	ECV falls materially when risk and valuation conditions deteriorate.
Scenario output	Maximum financing capacity	USD 2.30 million	USD 2.01 million	USD 1.60 million	Financing capacity remains conservative across all scenarios.
One-way sensitivity	Discount rate, r_n	10% → USD 2.19m	15% → USD 2.01m	25% → USD 1.78m	Higher discount rates reduce DCF and integrated value.
One-way sensitivity	Haircut, HC	15% → USD 2.28m	25% → USD 2.01m	45% → USD 1.47m	Haircuts have a direct linear effect on effective collateral value.
One-way sensitivity	Maximum advance rate, MAR	70% → USD 2.34m	60% → USD 2.01m	40% → USD 1.34m	Advance-rate policy directly controls lender exposure.
One-way sensitivity	Risk loading, ρ	10% → USD 2.13m	15% → USD 2.01m	25% → USD 1.77m	Token price declines as risk deductions rise.
One-way sensitivity	Trust factor, τ	10% → USD 2.10m	5% → USD 2.01m	0% → USD 1.91m	The governance premium has limited influence by design.

The sensitivity results show that haircut policy and maximum advance rate have particularly direct effects on financing capacity, while discount rate and aggregate risk loading reduce financing capacity through valuation and token-price channels. The trust factor improves collateral recognition, but its effect remains intentionally limited because the model does not allow governance quality to override weak financial fundamentals.

Because the framework was designed for inflationary economies, the findings included an inflation and foreign-exchange shock illustration. A 30% local-currency depreciation shock was combined with higher imported-input costs. Although replacement cost increased in hard-currency terms because imported machinery and logistics became more expensive, operating cash flow deteriorated, the risk reserve increased, the discount rate rose, the integrated asset value declined, and maximum financing capacity fell sharply.

Table 8. Inflation/FX shock, policy implications, and future research pathway

Dimension	Base case or proposed pathway	Shock, implication, or future output
Replacement cost, $\boldsymbol{V_g}$	USD 70m	USD 77m under 30% local-currency depreciation due to imported equipment and logistics cost pressure.
Annual operating cash flow	USD 8.0m	USD 6.8m when input costs rise faster than revenues.
Risk reserve	USD 3m	USD 5m due to FX, maintenance, and legal uncertainty.
Discount rate	15%	20% due to higher risk and convertibility premium.
Integrated value, $\boldsymbol{V_A}$	USD 52.65m	Approximately USD 47.87m under the shock.
Risk loading and trust factor	$\rho = 15\%,\ \tau = 5\%$	$\rho = 22\%,\ \tau = 4\%$under stressed conditions.
Haircut and MAR	25% haircut and 60% MAR	35% haircut and 50% MAR under stressed conditions.
Maximum financing capacity	USD 2.01m	Approximately USD 1.20m after inflation and FX stress.

Legal recognition of tokens and SPV rights	Token, asset, SPV, token-holder, and lender relationships must be legally defined.	Policymakers should clarify whether tokens represent ownership, beneficial interests, usufruct, lease receivables, debt claims, or contractual claims.
Security-interest registration	Pledged tokens must be enforceable in both the digital registry and the legal system.	Hybrid smart legal contracts should connect legal prose, operational parameters, and code; if code or an oracle fails, the legal contract must define rights and dispute resolution.
Permissioned infrastructure	Domestic capital mobilization and compliant asset finance should be prioritized.	Platforms should use verified participants, sanctions screening, AML/CFT controls, transaction monitoring, and auditable disclosure.
Investor protection	Disclosure, valuation, technical inspection, audited SPV statements, custody standards, insurance verification, transfer restrictions, and default procedures are required.	Disclosure must specify whether token holders own the asset, hold beneficial interests, receive cash flows, or hold contractual claims.
Market integrity	Industrial RWA tokens may function like securities, secured loan participations, or collective investment instruments.	Comparable investor-protection and prudential rules should apply under the principle of same activity, same risk, same regulatory outcome.
Phase I: legal and technical groundwork	0–12 months	Define token categories, eligible assets, SPV requirements, valuation standards, and pilot eligibility; output is a legal taxonomy and pilot rulebook.
Phase II: sandbox pilots	12–24 months	Launch limited industrial RWA pilots with permissioned participants, independent appraisals, and custodian reporting; output is operational evidence, data standards, and risk controls.
Phase III: collateral recognition	24–36 months	Permit regulated lenders to recognize approved RWA tokens subject to haircuts, MAR limits, and capital treatment; output is a bank-compatible collateral framework.
Phase IV: scaled market infrastructure	36–60 months	Integrate trading venues, Islamic finance structures, standardized disclosure, and interoperability with regulated payment rails; output is a domestic industrial RWA ecosystem.
Islamic finance pathway	Ijarah-style structure through an SPV	The SPV may hold beneficial interest or usufruct, issue tokens representing undivided rights, lease the asset back to the operating company, and distribute lease-linked returns subject to Shariah review.
Pilot validation	0–18 months	Use anonymized industrial-asset files, independent appraisals, SPV documents, lender credit-committee feedback, and observed pledge terms to validate risk loadings, haircuts, CITI scores, and MAR.
Market-data calibration	18–36 months	Use token transfer records, bid-ask spreads, auctions, appraisal updates, utilization data, and borrower performance to estimate liquidity discounts, trust premia, collateral volatility, and margin-call thresholds.
Stress testing in inflationary economies	18–36 months	Use inflation, FX depreciation, replacement-cost inflation, import restrictions, and sector cash-flow shocks to build scenario libraries and supervisory stress-test templates.
Legal and insolvency testing	24–48 months	Use sandbox cases, pledge tests, custodian default simulations, and token-holder priority analysis to develop model SPV documentation and enforceability opinions.
Islamic-finance implementation	24–48 months	Use Shariah-board reviews, lease or usufruct cash-flow data, sukuk-style SPV structures, and investor-demand surveys to create Shariah-compatible industrial RWA templates.
Cross-country comparison	36 months and beyond	Compare pilots in Iran, Turkey, Argentina, and other inflationary or FX-constrained economies to test external validity and generate policy guidance.

The inflation and FX shock confirms that inflation does not automatically increase collateral capacity. Although replacement cost can rise, lender-recognized hard-currency collateral value may fall when operating margins weaken, discount rates increase, liquidity deteriorates, legal uncertainty rises, and collateral haircuts become more conservative. This finding supports the core logic of the framework: valuation, risk adjustment, trust scoring, and collateralization must be integrated rather than treated as separate or static calculations.

The proposed framework deliberately constrained optimistic claims about tokenization. It did not assume that blockchain representation creates economic value by itself. Value was generated only when tokenization improved divisibility, transparency, pledge control, monitoring, investor access, settlement efficiency, or collateral administration while preserving legal enforceability. In the numerical case, a USD 52.65 million integrated asset value generated only USD 2.01 million of maximum collateralized financing after applying a limited token pledge, 15% aggregate risk loading, 5% trust adjustment, 25% haircut, and 60% maximum advance rate. This conservative outcome is more credible than a model suggesting that tokenization can unlock the entire value of an industrial asset.

The findings also show that governance can support collateral acceptance without dominating the model. The trust factor was capped at 10%, and weak governance received no positive premium. Poor governance was therefore not hidden behind a discretionary reputation multiplier; instead, it increased legal-operational risk, haircut risk, or collateral ineligibility. This design responds to a common weakness in tokenization models by converting institutional trust into a measurable, bounded, and auditable factor.

The findings further indicate that the framework remains conceptual and design-oriented. It does not rely on a dataset of executed industrial RWA transactions, and the numerical case is illustrative rather than an empirical market back-test. The model parameters, including industrial risk, liquidity risk, legal-operational risk, haircut weights, CITI weights, and trust-premium caps, require future validation using pilot data, bank credit files, observed token liquidity, realized default recoveries, and enforceability outcomes. Practical implementation risks also remain important, including oracle manipulation, delayed appraisals, incomplete maintenance records, conflicts between token registries and off-chain title records, cyber risk, sanctions and AML/CFT constraints, currency convertibility restrictions, tax uncertainty, and court treatment of token-holder rights in insolvency. These limitations reinforce the need for controlled pilots before broad policy adoption.

Discussion and Conclusion

The purpose of this study was to develop an integrated framework for the valuation, tokenization, and collateralization of industrial real-world assets (RWAs) in inflationary economies. The findings demonstrated that industrial assets can be transformed into collateralizable digital claims through a structured process that combines hybrid valuation techniques, risk-adjusted token pricing, institutional trust measurement, collateral haircuts, and lending-capacity controls. The most important finding was that the integrated valuation model produced a hybrid asset value of USD 52.65 million for the illustrative manufacturing production line, yet the resulting maximum financing capacity was only USD 2.01 million after the application of risk adjustments, trust calibration, collateral haircuts, and advance-rate restrictions. This result is particularly significant because it challenges overly optimistic assumptions frequently associated with tokenization. Rather than suggesting that tokenization unlocks the full economic value of an asset, the findings indicate that financially prudent tokenization creates a controlled and risk-sensitive mechanism for converting productive assets into lender-recognized collateral. This interpretation aligns with studies emphasizing that tokenization should be viewed as an enhancement of financial infrastructure rather than a replacement for traditional risk management and valuation principles (3-5).

A major contribution of the framework is its integration of multiple valuation methodologies into a single analytical architecture. The results demonstrated that reliance on any single valuation method would have produced potentially misleading conclusions. The DCF estimate generated a lower valuation because it reflected future cash-flow uncertainty, while the market and replacement-cost approaches generated higher values due to asset replacement characteristics and comparable transactions. The integrated valuation approach produced a balanced estimate that accounted simultaneously for cash-flow generation, replacement cost, market evidence, and remaining economic life. This finding is consistent with classical valuation theory, which argues that no single valuation method is sufficient for complex or specialized assets, particularly under conditions of uncertainty and information asymmetry (8, 9). The results therefore support the proposition that industrial RWAs require multidimensional valuation frameworks rather than simplified asset-pricing approaches commonly applied to standardized financial instruments.

Another important finding concerns the role of tokenization in enhancing asset divisibility and collateral mobility. The framework demonstrated how a large industrial asset can be divided into millions of digital units without altering the underlying economic value of the asset. This supports the broader literature on blockchain economics, which suggests that tokenization reduces transaction frictions, improves ownership granularity, and facilitates more efficient transfer of economic claims (3, 18). The findings also align with recent empirical and conceptual studies showing that tokenization can improve market accessibility and expand participation in previously illiquid asset classes (19, 21). However, unlike much of the existing literature, the present framework demonstrates that increased divisibility alone does not guarantee increased collateral value. Lending capacity remains constrained by risk assessment, legal enforceability, governance quality, and liquidity conditions.

The results further highlighted the importance of risk-adjusted token pricing. The application of industrial risk, liquidity risk, and legal-operational risk reduced the base token price from USD 10.00 to USD 8.50 before the institutional trust adjustment was applied. This finding underscores the reality that tokenized assets remain exposed to traditional financial risks despite being represented on blockchain infrastructure. The importance of liquidity risk is particularly noteworthy because industrial assets often lack active secondary markets. The literature on liquidity and collateral cycles demonstrates that asset value and financing capacity are strongly influenced by market liquidity conditions, particularly during periods of stress (10, 11). Similarly, research on decentralized finance has repeatedly emphasized that technological innovation does not eliminate liquidity constraints, collateral volatility, or market risk (4, 7). The present findings reinforce these observations by showing that risk deductions materially affect token prices and financing capacity.

One of the most innovative aspects of the study was the introduction of the Composite Institutional Trust Index (CITI). The results showed that governance quality can positively influence collateral acceptance through measurable dimensions such as smart-contract assurance, regulatory status, custodian quality, SPV transparency, and disclosure reliability. The trust adjustment increased the risk-adjusted token price from USD 8.50 to USD 8.93, representing a modest but meaningful enhancement in collateral value. Importantly, the trust premium was intentionally capped at 10%, ensuring that governance quality could not compensate for weak financial fundamentals. This finding is consistent with arguments that blockchain systems continue to depend on institutions, governance structures, and legal frameworks even when transaction verification is decentralized (13, 14). It also supports broader institutional perspectives suggesting that economic value depends not only on technological architecture but also on enforceable rights, transparency, and governance quality (15). The bounded nature of the trust premium is particularly important because it prevents the model from assigning unrealistic value to reputation or governance alone.

The collateralization results provide additional insight into the relationship between tokenization and secured lending. The findings revealed that a large industrial asset valued at more than USD 52 million produced only USD 3.35 million in effective collateral value after risk adjustment and haircut application, ultimately supporting a maximum financing capacity of approximately USD 2.01 million. This outcome reflects the prudential role of collateral haircuts and maximum advance rates in protecting lenders against valuation uncertainty, market illiquidity, and enforcement risk. The result is consistent with collateral theory, which argues that lending capacity depends not on nominal asset value but on the portion of value that can be reliably recovered in adverse circumstances (10, 12). The framework therefore contributes to the literature by demonstrating how tokenized industrial assets can be integrated into conventional collateral-management systems without abandoning established principles of secured lending.

The scenario analysis further demonstrated the sensitivity of tokenized collateral to changes in valuation, risk, and governance assumptions. Financing capacity varied from approximately USD 1.60 million under pessimistic conditions to USD 2.30 million under optimistic conditions. This range illustrates the importance of continuously monitoring both financial and governance variables. Similar conclusions have been reached in tokenomics research, which highlights the dynamic relationship among asset valuation, adoption, risk perception, and market participation (17). The findings also support recent studies emphasizing that tokenized asset systems require ongoing calibration of risk parameters and governance controls to maintain market confidence (19, 20). Consequently, the framework’s recursive structure, which allows updated information to affect token prices and collateral coverage, represents a practical advancement over static collateral models.

The inflation and foreign-exchange stress test produced one of the most important findings of the study. Although replacement costs increased under a 30% local-currency depreciation shock, financing capacity declined substantially from USD 2.01 million to approximately USD 1.20 million. This occurred because operating cash flows weakened, risk reserves increased, discount rates rose, and collateral conservatism intensified. The finding demonstrates that inflation does not automatically increase collateral value, even when asset prices rise. Instead, lender-recognized value depends on a combination of cash-flow performance, liquidity, legal enforceability, and macroeconomic risk. This observation is especially relevant for emerging and inflationary economies, where firms often possess valuable productive assets but face financing constraints due to economic instability. The result extends existing discussions of tokenization by showing that inflation-sensitive environments require integrated valuation frameworks capable of incorporating replacement cost, cash-flow deterioration, foreign-exchange risk, and liquidity adjustments simultaneously.

The findings also have implications for the broader evolution of digital finance. Recent studies have argued that tokenization may become a foundational element of next-generation financial infrastructure by improving settlement efficiency, reducing transaction costs, and enabling programmable ownership rights (18, 24). Empirical evidence from tokenized bonds suggests that blockchain-based issuance and trading may reduce operational inefficiencies and market frictions (22, 23). Similarly, real-estate tokenization studies indicate that fractional ownership can broaden market access and improve liquidity (21). The present study extends this literature by demonstrating how industrial assets, which have received comparatively little attention, can also participate in tokenized financial ecosystems. Unlike bonds or real estate, however, industrial assets require additional attention to maintenance quality, operational continuity, useful life, and technological obsolescence. The framework therefore contributes a novel perspective by integrating these considerations into a unified collateralization model.

The findings further support the argument that tokenization should complement rather than replace regulatory oversight. Embedded supervision and programmable compliance have been proposed as mechanisms through which regulatory requirements can be incorporated directly into digital financial systems (25). However, the results indicate that legal recognition, custody arrangements, disclosure standards, and enforcement procedures remain critical determinants of collateral acceptance. This observation aligns with research emphasizing that decentralized systems still depend on governance, regulation, and institutional legitimacy to achieve widespread adoption (6, 27). Consequently, the framework's reliance on SPV structures, custodial controls, disclosure requirements, and trust measurement reflects an institutional approach to tokenization that is consistent with both financial stability objectives and practical lending requirements.

Finally, the study contributes to ongoing discussions about blockchain-enabled asset-backed finance. Early blockchain research focused primarily on peer-to-peer digital cash and decentralized value transfer (1, 2). More recent scholarship has explored tokenized securities, DeFi protocols, and programmable financial markets (4, 5). The present findings suggest that the next stage of development may involve productive industrial assets serving as digitally represented collateral within regulated financial systems. By integrating valuation theory, collateral management, governance measurement, and tokenization technology, the framework offers a pathway for transforming underutilized industrial capital into a more accessible financing resource while maintaining prudent risk controls.

The study has several limitations that should be acknowledged. First, the framework is conceptual and design-oriented rather than empirically validated through a large sample of actual industrial RWA transactions. Second, the numerical case study is illustrative and should not be interpreted as evidence of existing market prices or financing outcomes. Third, many model parameters—including risk loadings, haircut weights, trust-factor calibration, and advance-rate limits—were selected using theoretically grounded assumptions rather than observed transaction data. Fourth, the framework assumes the existence of functioning legal, custodial, and technological infrastructures capable of supporting tokenized collateral systems. Finally, practical implementation challenges such as oracle manipulation, cyber risk, data quality issues, regulatory uncertainty, and jurisdiction-specific insolvency treatment remain unresolved and may materially affect real-world outcomes.

Future research should focus on empirical validation of the proposed framework using actual industrial asset portfolios, tokenized collateral transactions, and lender performance data. Researchers could estimate industrial risk, liquidity risk, and legal-operational risk parameters using observed default rates, collateral recoveries, and secondary-market trading activity. Additional studies should examine how different governance structures influence trust formation and lending outcomes across jurisdictions. Comparative investigations involving civil-law, common-law, and Islamic-finance systems would provide valuable insight into legal enforceability and asset-transfer mechanisms. Future work could also explore dynamic pricing models that update collateral values in real time using IoT data, maintenance records, and operational performance metrics. Finally, cross-country studies involving inflationary and non-inflationary economies would help assess the external validity and scalability of industrial RWA tokenization frameworks.

Financial institutions considering industrial RWA tokenization should adopt conservative valuation and collateral-management standards during early implementation phases. Independent appraisals, robust SPV structures, qualified custodians, and transparent disclosure practices should be treated as mandatory components of any tokenization program. Regulators should establish clear legal definitions for tokenized ownership rights, collateral recognition, and enforcement procedures before permitting widespread adoption. Industrial firms should ensure that maintenance records, insurance documentation, and operational performance data are continuously updated and independently verifiable. Pilot programs should be implemented within controlled regulatory environments before large-scale deployment. In addition, institutions should develop comprehensive monitoring systems that combine financial metrics, governance indicators, and collateral coverage thresholds to ensure that tokenized industrial assets remain reliable and bankable sources of financing over time.

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Authors' Contributions

All authors equally contributed to this study.

Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

All ethical principles were adheried in conducting and writing this article.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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