Стопански факултет

Социално-икономически анализи

Книга 1/2026 (29)

DOI: 10.54664/JWXF7598

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# BLOCKCHAIN AND SMART CONTRACTS IN THE FINANCIAL SECTOR: OPPORTUNITIES, RISKS, AND REGULATORY CHALLENGES — A CASE STUDY OF GERMANY

**Abstract:** The financial sector is shifting from centralised intermediation towards decentralised architectures enabled by blockchain and smart contracts. This paper examines their impact on financial intermediation, using Germany as a case study. Combining theoretical analysis with empirical evidence, it identifies a transition from an early focus on payment efficiency to a broader trust-based infrastructure centred on tokenisation, identity management, and interoperable data exchange. The findings show important operational benefits, including faster settlement and lower transaction costs, but also reveal a persistent German adoption gap: high strategic recognition of blockchain coexists with limited operational deployment. The study further identifies major barriers, including software vulnerabilities, oracle dependence, and jurisdictional uncertainty. It concludes that blockchain-based finance requires a hybrid governance model that combines technological automation with legal certainty, regulatory oversight, and institutional trust.

**Keywords:** Blockchain technology; Smart contracts; Financial intermediation; Germany; Decentralised finance (DeFi); Tokenisation; Regulatory challenges; Legal liability; Digital trust; MiCA

## 1. Introduction

The financial sector is undergoing a major transformation as traditional centralised structures increasingly interact with decentralised digital systems, particularly within the framework of Decentralised Finance (DeFi). Unlike conventional finance, which relies on banks and other intermediaries to validate and execute transactions, DeFi operates through blockchain technology and smart contracts. Blockchain provides a decentralised and immutable ledger for secure and transparent record-keeping, while smart contracts enable the automatic execution of contractual obligations once predefined conditions are met. Together, these technologies are reshaping payments, lending, investment, and asset management by introducing new forms of automation, transparency, and disintermediation.

Within this broader context, this study focuses on Germany as a case study. Germany is particularly relevant because, as one of Europe's leading economic and financial centres, it reflects the growing tension between rapid technological innovation and the legal and institutional frameworks that continue to govern financial markets. Although blockchain and smart contracts offer significant opportunities in terms of efficiency, transparency, automation, and lower transaction costs, they also raise complex legal

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and regulatory questions concerning enforceability, liability, consumer protection, data protection, financial supervision, and institutional accountability.

The research problem therefore lies in the widening gap between the speed of technological development and the slower adaptation of legal and regulatory structures in the financial sector. This issue is especially important for banks, regulators, and policymakers in Germany, who need to understand blockchain and smart contracts not merely as digital tools, but as structural developments capable of transforming financial intermediation and regulatory practice. Accordingly, the central research question of this study is formulated as follows: to what extent do blockchain technology and smart contracts transform the functioning of financial institutions in Germany, and how can legal and regulatory frameworks respond effectively to this transformation?

This main question gives rise to several subsidiary issues, including the conceptual foundations of blockchain and smart contracts, their impact on the traditional role of financial intermediaries, the opportunities they create for the financial sector, and the legal and regulatory challenges arising from their use in the German financial context.

Methodologically, this study adopts a qualitative descriptive and analytical approach, supported by a documentary case study of Germany. The descriptive component is used to clarify the conceptual foundations of blockchain technology and smart contracts and to explain their relevance to decentralised finance, transaction automation, and the transformation of financial intermediation. The analytical component examines the opportunities, risks, and regulatory challenges associated with these technologies in the financial sector. Germany was selected as a case study because it represents a highly regulated European financial market where blockchain-based innovation must be assessed in relation to legal certainty, consumer protection, data protection, financial stability, and supervisory oversight. The study relies on secondary sources, including academic literature, legal and regulatory materials, institutional reports, and statistical data related to blockchain adoption and perceived barriers in Germany, which are analysed through a documentary and thematic approach.

## 2. Theoretical Framework: Blockchain and Smart Contracts in Finance

This section clarifies the theoretical foundations of blockchain technology and smart contracts, which form the core infrastructure of decentralised financial innovation. Their significance in finance lies in enabling transactions, contractual execution, and record-keeping through decentralised digital mechanisms rather than traditional centralised intermediaries.

### 2.1 Blockchain in Finance

Blockchain may be defined as a decentralised and distributed ledger technology through which transactions are recorded, verified, and stored across a network of participants without the need for a single central authority. [1] In the financial sector, this technological architecture introduces a new model of trust, since verification is ensured collectively by the network rather than by a bank, clearing house, or other intermediary institution.[2]This development has major implications for the organisation of financial activities, particularly in areas such as payments, lending, trading, settlement, and asset management.[3]

Three characteristics are especially central to the financial significance of blockchain. The first is decentralisation, which means that control over transaction validation and data storage is distributed among multiple nodes rather than concentrated in one institution.[4]The second is immutability, which

[1] **Al-Dulaimi, A., et al.** I. Introduction. In: Al-Dulaimi, A., O. A. Dobre, and C.-L. I. (eds.). *Blockchains: Empowering Technologies and Industrial Applications*. Hoboken, NJ**:** Wiley-IEEE Press, 2023, https://doi.org/10.1002/9781119781042.ch.

[2] **Patel, R., et al.** Blockchain in banking and finance: A bibliometric review. Research in International Business and Finance [online], vol. 62, 2022, 101718. https://doi.org/10.1016/j.ribaf.2022.101718

[3] **Ryabov, O., et al.** Decentralized Finance (DEFI) as the Basis for the Transformation of the Financial Sector of the Future. In: Proceedings of the 3rd International Scientific Conference on Innovations in Digital Economy, Saint Petersburg, Russia, 14–15 October 2021. ACM International Conference Proceeding Series, NY. 2021, pp. 387–394. https://doi.org/10.1145/3527049.3527080

[4] **Aghili, S.** (ed.). *Leveraging Blockchain Technology: Governance, Risk, Compliance, Security, and Benevolent Use Cases.* 1st edition. Boca Raton: CRC Press, 2024. https://doi.org/10.1201/9781003462033

refers to the practical difficulty of altering data once it has been validated and recorded on the chain, thereby enhancing traceability and trust in transaction records.[5]The third is transparency, since blockchain networks generally allow transactions to be viewed and verified by participants in the network, which improves auditability and reduces informational asymmetry in financial operations.[6]Taken together, these characteristics explain why blockchain has become a foundational element in the rise of Decentralised Finance (DeFi) and other digital financial infrastructures.[7]

**2.2 Smart Contracts in Finance**

If blockchain provides the infrastructure, smart contracts provide the operational logic through which financial relationships can be executed automatically. Smart contracts are generally understood as self-executing software programmes deployed on a blockchain, in which the terms and conditions of an agreement are translated into coded instructions.[8] Once the required conditions are fulfilled, the programme executes the corresponding action automatically, in principle without the need for direct human intervention or a third-party intermediary.[9]In this respect, smart contracts do not merely document obligations; they are capable of implementing and implementing them through code.[10]

Their importance in finance lies in several core properties. First, they enable automation, since contractual clauses may be executed immediately once predefined criteria are satisfied.[11] Secondly, they rely on a logic of deterministic execution, commonly described in simplified form as an "if–then" structure: if a specified condition is met, then a programmed consequence is triggered.[12] Thirdly, they reduce the need for intermediaries such as brokers, escrow agents, and certain administrative units within financial institutions, thereby lowering transaction and enforcement costs.[13]Finally, smart contracts are highly programmable, which makes them suitable for a wide range of financial applications, including digital payments, token issuance, decentralised lending, trading protocols, insurance mechanisms, and asset transfers.[14]

**2.3 The Automation of Financial Transactions**

One of the most significant contributions of smart contracts to modern finance is their ability to automate financial transactions through encoded conditional logic.[15] This automation represents a substantial departure from conventional financial systems, where the performance of contractual obligations often depends on manual verification, administrative processing, and institutional approval.[16]By contrast, in blockchain-based environments, the smart contract can trigger execution once the required inputs are confirmed.[17]

A useful illustration is the case of automated loan disbursement. Under a smart-contract model, the software may be programmed so that, if predetermined requirements are fulfilled, such as collateral valuation, identity verification, or confirmation of agreed financial conditions, the contract automatically

[5] **Bedi, P., et al.** DBESN: A novel model for detecting and identifying malicious code in a smart contract. *Blockchain: Research and Applications*, vol. 6 (4), 2025, 100304. https://doi.org/10.1016/j.bcra.2025.100304

[6] **Al-Dulaimi, A., et al.** Op. cit.

[7] **Patel, R., et al.** Op. cit.

[8] **Bedi, P., et al.** Op. cit.

[9] **El Hassouni, L., A. Ouchekkir.** Smart Contracts: An Emerging Business Model in Decentralized Finance. In: Motahhir, S., and B. Bossoufi (eds.). *Digital Technologies and Applications. ICDTA 2023. Lecture Notes in Networks and Systems,* vol. 668. Cham **:** Springer, 2023, pp. 197–207. https://doi.org/10.1007/978-3-031-29857-8_20

[10] **Mik, E.** The Sense and Nonsense of Smart Contracts. In: Lee, J., and J.-A. Lee (eds.). *Web3 Governance: Law and Policy.* Abingdon, Oxon/New York**:** Routledge, 2025, pp. 46–68. https://doi.org/10.4324/9781032618975-5.

[11] **El Hassouni, L., and A. Ouchekkir.** Op. cit.

[12] **Bedi, P., et al.** Op. cit.

[13] **El Hassouni, L., and A. Ouchekkir.** Op. cit.

[14] **Guelida, O., et al.** Smart Contracts in Finance and Banking Systems in the Era of Industry 5.0: A Systematic Review. In**:** Chakir, A., R. Bansal, and M. Azzouazi (eds.). *Industry 5.0 and Emerging Technologies: Transformation Through Technology and Innovations. Studies in Systems, Decision and Control*, vol. 565. Cham: Springer, 2024, pp. 317–346. https://doi.org/10.1007/978-3-031-70996-8_16

[15] **Bedi, P., et al.** Op. cit.

[16] **Guelida, O., et al.** Op. cit.

[17] **El Hassouni, L., and A. Ouchekkir.** Op. cit.

initiates the release of funds, calculates repayment schedules, or applies interest obligations .[18]Although this example is illustrative, it reflects the wider logic of smart-contract-based finance, where financial actions are embedded in code and executed according to predefined rules.[19] Such a model may improve speed, reduce operational errors, and strengthen procedural consistency, while at the same time raising important legal and regulatory questions concerning accountability, enforceability, and risk allocation.[20]

**2.4 Analytical Relevance to the Financial Sector**

From a theoretical perspective, blockchain and smart contracts should not be understood merely as technical tools, but as mechanisms capable of reshaping the very structure of financial intermediation.[21] By decentralising trust, automating execution, and reducing reliance on traditional institutional actors, they challenge long-established assumptions regarding the role of banks, the nature of contractual execution and enforcement, and the regulatory boundaries of financial markets.[22]For this reason, any serious study of their impact on the financial sector must begin with a clear conceptual understanding of these technologies before moving to their practical, legal, and regulatory implications.[23]

## 3. Opportunities of Blockchain and Smart Contracts in the Financial Sector

### 3.1 The Early Opportunity Structure: Mapping Institutional Priorities

The early opportunity structure of blockchain in finance reflected a strategic focus on mitigating institutional friction. As shown in Figure 1, a 2016 global survey of financial institutions identified international money transfers (60%) as the primary application area, followed by securities clearing and settlement (23%) and KYC/AML compliance (20%). Other significant functions included transparency (19%), decentralised notarisation (16%), and fraud deterrence (15%).

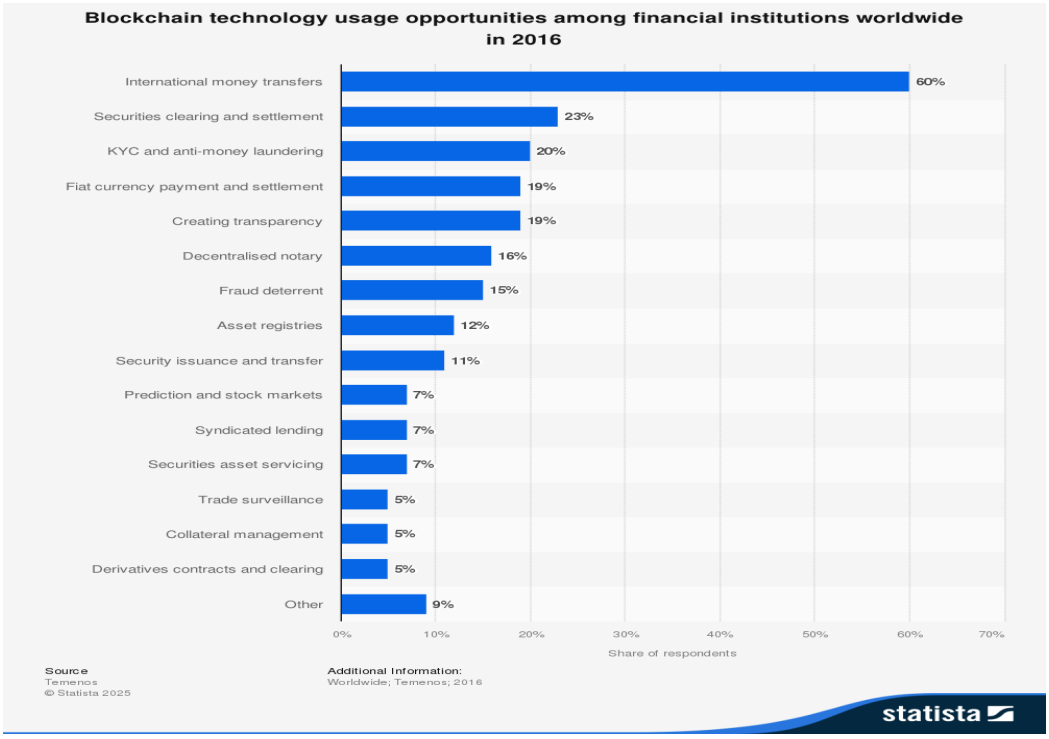


**Figure 1.** Blockchain technology usage opportunities by financial institutions, 2016

**Source: Statista Research Department:** Blockchain technology usage opportunities by financial institutions 2016 [Online]. Statista [Accessed**:** 18 April 2026], 2016. Available at**:** https://www.statista.com/statistics/648044/blockchain-usage-by-financial-institutions/.

[18] **Bedi, P., et al.** Op. cit.
[19] **Guelida, O., et al.** Op.cit.
[20] **Mik, E.** Op. cit.
[21] **Patel, R., et al.** Op. cit.
[22] **Ryabov, O., et al.** Op. cit.
[23]**Guelida, O., et al.** Op. cit.

From an analytical perspective, these figures suggest that institutional interest was initially driven by three strategic priorities:

- Payment Efficiency: The dominance of cross-border payments (60%) highlights the industry's urgency to bypass the costly and fragmented correspondent banking system.
- Post-Trade Infrastructure: The emphasis on clearing and settlement (23%) suggests a shift toward "atomic settlement," that is, simultaneous and final settlement of transactions, reducing the multi-day delays inherent in manual reconciliation.
- Trust and Compliance: The clustering of KYC, transparency, and fraud deterrence (combined ~54%) confirms that blockchain was perceived as a "trust layer" for verifiable records and auditability, rather than merely a speculative payment rail.

This early "opportunity map" laid the foundation for current adoption patterns in advanced economies like Germany, where the focus has evolved from simple transfers toward complex tokenization and interoperable data exchange (see Section 3.4).

To make the structure clearer for analytical purposes, the 2016 opportunities may be regrouped into three strategic pillars.

**Table 1.** Analytical regrouping of blockchain opportunities in finance based on the 2016 survey

| Strategic pillar | Main 2016 applications | Interpretation |
|---|---|---|
| **Payments and settlement infrastructure** | International money transfers; securities clearing and settlement; fiat currency payment and settlement; security issuance and transfer; securities asset servicing; collateral management; derivatives contracts and clearing | Blockchain was first perceived as a means of reducing delay, settlement risk, and intermediation costs in core financial plumbing. |
| **Compliance, trust, and record integrity** | KYC/AML; creating transparency; decentralised notary; fraud deterrent; asset registries; trade surveillance | Institutions also viewed blockchain as an infrastructure for traceability, verifiable records, and more reliable compliance processes. |
| **New market architectures** | Prediction and stock markets; syndicated lending | A smaller but significant set of uses pointed towards new programmable market forms and digitally native financial intermediation. |

***Note**: This regrouping is an analytical interpretation based on the 2016 survey results reported in the source.*

### 3.2 From Expected Opportunity to Demonstrated Efficiency

What appeared as an anticipated opportunity in 2016 is supported by more recent empirical and conceptual work. The literature consistently shows that blockchain can accelerate clearing and settlement by replacing multi-stage reconciliation with real-time or near-real-time validation. In trade finance simulations, settlement duration has been reported to fall from 8.4 days to 0.2 days, while smart-contract-enabled market infrastructures support near-instantaneous forms of delivery-versus-payment and atomic settlement. These developments help explain why clearing, settlement, and international transfers occupied such a prominent place in the 2016 opportunity ranking.

The same logic applies to cost reduction. Cross-border payments are among the most expensive segments of traditional finance because they depend on multiple intermediaries and fragmented verification processes. The literature reviewed in this study shows that blockchain can reduce reliance on correspondent banking, streamline transfer chains, and substantially lower transaction costs. One trade finance study reports a reduction in average transaction costs from US$1,209 to US$82 when blockchain replaces paper-based procedures. Accordingly, the prominence of international transfers in the 2016 dataset should be read not as an isolated preference, but as an early recognition of one of blockchain's strongest comparative advantages.

**3.3 Financial Inclusion and the Expansion of the Opportunity Frontier**

Although financial inclusion did not appear explicitly among the most highly ranked institutional uses in the 2016 survey, more recent literature has considerably broadened the opportunity frontier. Current studies increasingly associate blockchain and DeFi with mobile-based access to financial services, lower-cost remittances, decentralised lending, digital wallets, and alternative identity solutions for underserved populations. This suggests that the financial significance of blockchain has evolved from a relatively narrow concern with institutional efficiency towards a broader developmental and accessibility agenda. In this sense, the 2016 opportunity structure captured the first institutional wave, whereas later research points to a second wave centred on inclusion and digitally mediated access.

**3.4 The German Case: Perceived Blockchain Potential and Corporate Adoption Signals**

Germany serves as a particularly relevant case study, reflecting the broader tension between the recognition of blockchain's potential and the slower pace of institutional integration. This section synthesises layered evidence from corporate perception indicators (2024–2025), perceived application potential (2023), and ecosystem development (2018) in order to map Germany's blockchain trajectory.

**3.4.1 Perceived Economic Importance and Current Adoption in Germany**

Recent indicators for 2024–2025 reveal a significant gap between strategic legitimacy and operational reality. While 70% of German firms in 2024 and 66% in 2025 viewed blockchain as economically important, actual deployment remained limited, rising only from 3% to 6%. Notably, the share of firms discussing or planning blockchain adoption declined from 23% to 19%. This suggests that although blockchain has achieved institutional legitimacy, its implementation may remain constrained by regulatory uncertainty, integration costs, and the absence of mature business cases. For the financial sector, this situation highlights the need for clearer regulatory frameworks capable of bridging the gap between perceived importance and active use.

**3.4.2 Perceived Blockchain Potential by Application Area in Germany**

To support the analysis, the main application data may be presented as follows:

**Table 2.** Perceived blockchain potential by application area in Germany, 2023

| Application area | Rather high potential (%) | Very high potential (%) | Combined high potential (%) |
|---|---|---|---|
| **Traceability of activities across value-chain partners** | 35 | 63 | 98 |
| **Identity management for persons, machines, or sensors** | 57 | 39 | 96 |
| **Interoperable interface for data exchange in data analytics** | 51 | 45 | 96 |
| **Data quality management** | 51 | 36 | 87 |
| **Secure issuance of certificates and attestations** | 27 | 58 | 85 |
| **IoT transaction system with decentralised data trading** | 37 | 48 | 85 |
| **Tokenisation of real assets and financial securities** | 41 | 44 | 85 |
| **Intermediary-free digital marketplaces** | 42 | 42 | 84 |
| **Fundraising** | 34 | 39 | 73 |

**Source: DUFFIN, E.:** Potenzial von Blockchain in Unternehmen nach Anwendungsbereich in Deutschland 2023 [Online]. Statista [Accessed**:** 18 April 2026], 2024. Available at **:**https://de.statista.com/statistik/daten/studie/1575383/umfrage/potenzial-von-blockchain-in-unternehmen-nach-anwendungsbereich/.

***Note****: adapted from Bitkom Research (2023), based on companies in Germany with at least 50 employees that use blockchain, plan its adoption, or discuss its implementation.*

**3.4.3 Germany's Blockchain Entrepreneurial Ecosystem: A Historical Signal**

Germany's innovation trajectory is rooted in an early entrepreneurial base. By 2018, the country hosted 120 blockchain start-ups, with a strong concentration in Berlin (64). Notably, the presence of Frankfurt am Main (10) — Germany's financial capital — established an early link between blockchain

innovation and financial geography (Figure 2). This historical ecosystem suggests that Germany's current adoption phase is built on more than a decade of technical experimentation, particularly through Initial Coin Offerings (ICOs), which financed 45% of these early ventures.

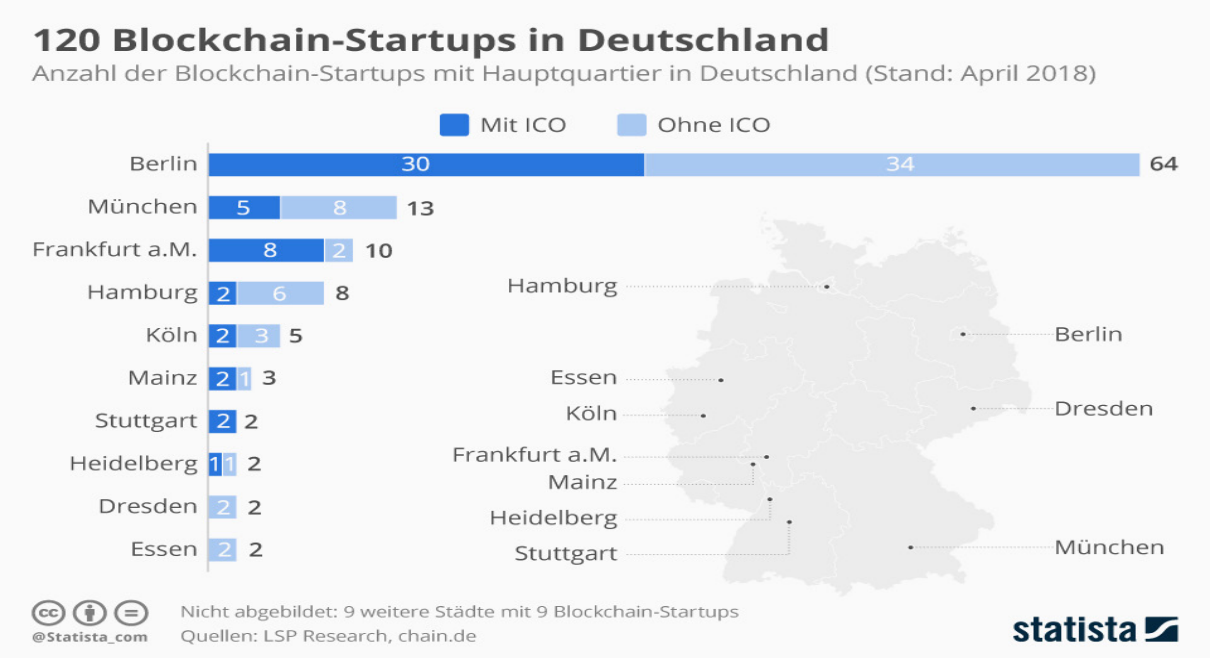


**Figure 2.** Distribution of 120 Blockchain Startups Across Major German Cities, April 2018

**Source: BRANDT, M.:** 120 Blockchain-Startups in Deutschland [Online]. Statista [Accessed: 18 April 2026], 2018. Available at: https://de.statista.com/infografik/13718/blockchain-startups-in-deutschland/.

The German evidence supports a nuanced interpretation: Germany is a "structured environment" where blockchain has achieved strategic legitimacy but has not yet reached operational normalisation. For the financial sector, this indicates that blockchain's transformative potential lies not merely in faster payments, but in creating a broader architecture for digital coordination. This includes tokenised assets, verifiable credentials, and automated market interactions - functions that form the core of modern financial infrastructure. However, the persistent gap between recognition and adoption suggests that technological promise remains contingent on institutional maturity, particularly legal certainty, interoperability standards, and organisational readiness. Thus, Germany serves as a valuable case for analysing the tension between borderless innovation and regulated financial stability.

## 4. Technical, Regulatory, Legal, and Jurisdictional Challenges of Blockchain and Smart Contracts in Finance

Despite their potential, blockchain and smart contracts face significant technical and institutional constraints. In financial systems, where these technologies govern payments, collateral, and automated execution, any weakness in code, data feeds, or privacy design may generate immediate financial, operational, and regulatory risks.[24, 25]

[24] **Arsat, N., et al.** Smart Contracts Vulnerabilities and Countermeasures in Blockchain Security. In**:** 2025 *International Conference on Metaverse and Current Trends in Computing* (ICMCTC 2025), Subang Jaya, Malaysia, 2025, pp. 1–6. https://doi.org/10.1109/ICMCTC62214.2025.11196566

[25] **Atiyah, G. A., et al.** Enforcement of smart contracts in cross-jurisdictional transactions. *International Journal of Law and Management*, vol. 68 (2), 2026, pp. 319–344. https://doi.org/10.1108/IJLMA-06-2024-0220.

**4.1 Software Vulnerabilities and Smart Contract Risk**

Smart contracts inherit traditional software defects but apply them to high-value financial assets. Recurring vulnerabilities — such as re-entrancy, logic flaws, and weak access control — can lead to unauthorised transfers or frozen funds. The challenge is intensified by immutability: unlike conventional software, blockchain-based contracts are difficult to patch after deployment. This “immutability paradox” means that even technically sound code can be compromised by environment-level weaknesses, necessitating rigorous auditing and multi-layered testing rather than treating smart contracts as simple plug-and-play automation tools.[26, 27, 28]

**4.2 The Oracle Problem and Dependence on External Data**

A structural vulnerability arises from dependence on oracles, namely external mechanisms that feed off-chain data, such as exchange rates, asset prices, or identity verification, into the blockchain. If an oracle provides false, delayed, or manipulated information, the smart contract may execute outcomes that are legally and economically problematic. This “oracle problem” creates a difficult trade-off between decentralisation and data reliability, raising critical questions about liability: who is responsible when a contract executes correctly based on defective external data? [29, 30, 31, 32]

**4.3 Privacy, Transparency, and Data Protection**

Blockchain’s inherent transparency, designed to foster trust, often conflicts with the financial sector’s requirements for confidentiality and data minimisation. While pseudonymity offers some protection, transaction histories remain linkable, creating privacy risks. Furthermore, immutability may conflict with legal mandates such as the right to erasure under the GDPR and other data-subject rights. While privacy-enhancing technologies, such as zero-knowledge proofs (ZKPs), offer potential solutions, they involve complex trade-offs in performance and cost. The central challenge remains balancing verifiable auditability with regulatory compliance and institutional confidentiality.[33, 34, 35]

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[26] **Gurjar, A., B. R. Chandavarkar**. Smart Contract Vulnerabilities and Detection Methods: A Survey. In: *2024 15th International Conference on Computing Communication and Networking Technologies* (ICCCNT 2024), Kamand, India, 24–28 June 2024. IEEE, 2024, pp. 1–7. https://doi.org/10.1109/ICCCNT61001.2024.10724246

[27] **Tantikul, P., S. Ngamsuriyaroj.** Exploring Vulnerabilities in Solidity Smart Contract. In**:** *Proceedings of the 6th International Conference on Information Systems Security and Privacy* (ICISSP 2020), Valletta, Malta, SciTePress, 2020, pp. 317–324. Available at: https://www.scitepress.org/Papers/2020/89098/89098.pdf

[28] **Raza, A. R., et al.** Unveiling SCARS: Smart Contract Audit Revelations and Security Exploits. In**:** *2025 International Conference on Communication Technologies* (ComTech 2025), Rawalpindi, Pakistan, 2025, pp. 1–6. https://doi.org/10.1109/ComTech65062.2025.11034518

[29] **Al-Breiki, H., et al.** Trustworthy Blockchain Oracles**:** Review, Comparison, and Open Research Challenges. *IEEE Access*, vol. 8, 2020, pp. 85675–85685. https://doi.org/10.1109/ACCESS.2020.2992698

[30] **Eskandari, S., et al.** SoK: Oracles from the Ground Truth to Market Manipulation. In**:** *Proceedings of the 3rd ACM Conference on Advances in Financial Technologies* (AFT 2021), New York: ACM, 2021, pp. 127–141. https://doi.org/10.1145/3479722.3480994

[31] **Calderón-Marenco, E. A., et al.** Regulatory and Technological Challenges of Oracles Applied to Smart Contracts. *Revista Jurídica Austral*, vol. 6 (2), 2025, pp. 977–1009. https://doi.org/10.26422/rja.2025.0602.cal

[32] **Nguyen, M. V., et al.** Blockchain Oracles**:** Implications for Smart Contracts in Legal Reasoning and Addressing the Oracle Problem. In: *Proceedings of the 12th International Symposium on Information and Communication Technology* (SOICT 2023). New York**:** ACM, 2023, pp. 296–303. https://doi.org/10.1145/3628797.3628870

[33] **Schellinger, B., et al.** Yes, I Do: Marrying Blockchain Applications with GDPR. In**:** *Proceedings of the 55th Hawaii International Conference on System Sciences*, 2022, pp. 4631–4640. https://doi.org/10.24251/ HICSS.2022.563 **Giannopoulou, A.** Putting Data Protection by Design on the Blockchain. *European Data Protection Law Review*, vol. 7 (3), 2021, pp. 388–399. https://doi.org/10.21552/ edpl/2021/3/7

[34] **Balamurugan, G., et al.** A Survey on Privacy Preserving and Trust Building Techniques of Blockchain-Based Systems. In**:** Lakshmi, D., and A. K. Tyagi (eds.). *Privacy Preservation and Secured Data Storage in Cloud Computing*. Hershey, PA**:** IGI Global, 2023, pp. 430–457. https://doi.org/10.4018/979-8-3693-0593-5.ch019

[35] **Balamurugan, G., A. K. Tyagi, and Richa.** A Survey on Privacy Preserving and Trust Building Techniques of Blockchain-Based Systems. In: Lakshmi, D., and A. K. Tyagi (eds.). Privacy Preservation and Secured Data Storage in Cloud Computing [online]. Hershey, PA: IGI Global, 2023, pp. 430–457 [Accessed**:** 02.05.2026]. Available at**:** https://doi.org/10.4018/979-8-3693-0593-5.ch019.

### 4.4 Scalability and performance Constraints

Financial systems require high throughput, low latency, and rapid finality — demands that often clash with blockchain's decentralised architecture. This challenge is commonly explained by the "Blockchain Trilemma," which posits that maximising decentralisation, security, and scalability simultaneously is architecturally difficult. For regulated institutions, this creates a critical design trade-off: a secure but slow network is commercially unviable, while a fast but institutionally fragile one fails to meet resilience standards. Consequently, scalability remains a fundamental hurdle to integrating blockchain into high-volume mainstream finance.[36, 37, 38]

**Table 3.** Integrated challenge map for blockchain and smart contracts in finance

| Challenge category | Core problem | Financial implication |
|---|---|---|
| **Software vulnerabilities** | Bugs, flawed logic, weak access control, immutable deployment | Loss of funds, faulty execution, operational and reputational risks |
| **Oracle dependence** | Reliance on external data feeds that may be delayed, false, or manipulated | Incorrect settlement, mispriced contracts, disputed outcomes |
| **Privacy versus transparency** | Public verifiability may conflict with confidentiality and data protection | Exposure of sensitive financial information and compliance risk |
| **Scalability** | Limited throughput, latency, and architectural trade-offs | Reduced suitability for high-volume financial infrastructures |
| **Liability ambiguity** | Unclear attribution of responsibility when code or infrastructure fails | Difficulties in redress, dispute resolution, and risk allocation |
| **Cross-border jurisdiction** | No clear territorial nexus for blockchain disputes | Uncertainty over applicable law, forum, and enforcement |

**Source**: **Author's compilation and synthesis** based on the existing literature, particularly: **Arsat et al.**, 2025; **Gurjar and Chandavarkar**, 2024; **Al-Breiki et al.**, 2020; **Eskandari et al.**, 2021; **Schellinger et al.**, 2022; **Giannopoulou**, 2021; **Wilkie and Smith**, 2021; **Mssassi and Abou El Kalam**, 2025; **Mik**, 2025; **Atiyah et al.**, 2026; and **Ruiz Rodríguez**, 2022.

### 4.5 Evidence from Germany: Empirical Barriers to Blockchain Adoption

Empirical evidence from Germany (2023) suggests that blockchain adoption is hindered more by institutional and human capital gaps than by the technology itself. As shown in Table 4, the dominant barriers include a shortage of qualified personnel (84%), lack of technical know-how (82%), and legal uncertainty (76%). These findings suggest that the primary obstacles to diffusion are rooted in institutional unreadiness and a lack of regulatory clarity.

A second cluster of barriers concerns governance and maturity. Significant hurdles include data-protection requirements (72%), IT-security requirements (70%), and the absence of reliable use cases (67%). Notably, insufficient support from top management (27%) and the superiority of alternative technologies (6%) were rarely cited. This pattern indicates that German firms — including those in the financial sector — do not dismiss blockchain as an inferior technology; rather, its adoption is delayed by capability gaps, legal ambiguity, and the lack of standardised implementation pathways.

[36] **Wilkie, A., S. S. Smith.** Blockchain: Speed, Efficiency, Decreased Costs, and Technical Challenges. In**:** Baker, H. K., E. Nikbakht, and S. S. Smith (eds.). *The Emerald Handbook of Blockchain for Business*. Bingley**:** Emerald Publishing Limited, 2021, pp. 157–170. https://doi.org/10.1108/978-1-83982-198-120211014

[37] **Mssassi, S., A. Abou El Kalam.** The Blockchain Trilemma: A Formal Proof of the Inherent Trade- Offs Among Decentralization, Security, and Scalability. *Applied Sciences*, vol. 15 (1), 2025, 19. https://doi.org/10.3390/app15010019

[38] **Chiedu, C. C., et al.** A Survey on On-Chain-Off-Chain Scalability in Blockchain. In: *2025 IEEE 11th Conference on Big Data Security on Cloud* (BigDataSecurity 2025). IEEE, 2025, pp. 71–82. https://doi.org/10.1109/BigDataSecurity66063.2025.00011.

**Table 4.** Main challenges in the use of blockchain in companies in Germany, 2023

| Challenge | Share of respondents (%) |
|---|---|
| **Lack of qualified personnel** | 84 |
| **Lack of technical know-how** | 82 |
| **Legal uncertainties** | 76 |
| **Data-protection requirements** | 72 |
| **IT-security requirements** | 70 |
| **No reliable use cases** | 67 |
| **Blockchain technology is not yet mature** | 64 |
| **High investment needs / lack of budget** | 63 |
| **Insufficient standardisation of blockchain applications** | 61 |
| **Lack of performance or scalability** | 53 |
| **Lack of time** | 29 |
| **Insufficient support from top management** | 27 |
| **Alternative technologies are superior** | 6 |

**Source: DUFFIN, E.:** Herausforderungen im Einsatz von Blockchain in Unternehmen in Deutschland 2023 [Challenges in the use of blockchain in companies in Germany 2023] [Online]. Statista, 2024. Available at **:** https://de.statista.com/statistik/daten/studie/1578760/umfrage/herausforderungen-von-blockchain-in-unternehmen/.

***Note:*** *Based on Bitkom Research data (2023); n=653 companies in Germany with ≥50 employees. Multiple responses were possible.*

### 4.6 Legal Status, Liability, and the Limits of “Code is Law”

While “code is law” describes the operational rigidity of smart contracts, it does not displace formal legal frameworks. Automated execution lacks the interpretive flexibility of traditional contract law, which relies on doctrines such as good faith, consent, and intention. In finance, this creates a liability gap: when code malfunctions or produces unfair outcomes, attributing responsibility among developers, oracles, platform operators, and contracting parties becomes complex. The immutability of blockchain intensifies this challenge, as errors may persist and cause financial damage before legal remedies can intervene.[39, 40]

To mitigate these risks, scholars increasingly propose hybrid models in which conventional legal agreements complement smart-contract code or override it in specific circumstances, thereby reintroducing remedial safeguards. Others suggest structured governance mechanisms, such as rollback procedures or legal oversight for blockchain environments. Ultimately, while smart contracts automate contractual performance, they do not eliminate the need for legal accountability; instead, they make the allocation of responsibility more complex and more urgent in financial applications.[41 42 43]

### 4.7 Jurisdiction and Cross-Border Enforceability

Jurisdiction remains a critical hurdle for blockchain-based finance due to the absence of an inherent territorial nexus. Unlike traditional contracts, distributed ledgers operate across borderless networks, complicating the determination of applicable law and competent courts. In the financial sector — where

[39] **Mik, E.** Op. cit.

[40] **Jin, S.** The Paradigm Logic of Blockchain Governance. *Technology in Society*, vol. 78, 2024, 102681. https://doi.org/10.1016/j.techsoc.2024.102681.

[41] **Kumi, L., et al.** State-of-the-Art Review of Blockchain Applications for Construction Safety: Opportunities, Challenges, and Future Directions. *Safety Science*, vol. 191, 2025, 106966. https://doi.org/10.1016/j.ssci.2025.106966

[42] **Böhmecke-Schwafert, M.** The Role of Blockchain for Trade in Global Value Chains: A Systematic Literature Review and Guidance for Future Research. *Telecommunications Policy*, vol. 48 (9), 2024, 102835. https://doi.org/10.1016/j.telpol.2024.102835

[43] **Bovenzi, G., et al.** Blockchain Performance in Industry 4.0: Drivers, Use Cases, and Future Directions. *Journal of Industrial Information Integration*, vol. 36, 2023, 100513. https://doi.org/10.1016/j.jii.2023.100513

tokenised assets and decentralised lending are inherently global — these difficulties are magnified by pseudonymity and the uncertain legal location, or lex situs, of digital assets. While solutions such as express governing-law clauses and tailored arbitration mechanisms are emerging, they remain partial fixes. Without global legal harmonisation, the structural tension between borderless digital infrastructures and territorial legal systems will persist.[44] [45]

**Table 5.** Regulatory and legal challenges of blockchain in finance

| Issue | Main concern | Relevance to finance |
|---|---|---|
| **Legal status of code** | Automated execution may operate rigidly without legal interpretation | Challenges contract doctrines based on consent, context, and reasonableness |
| **Liability for errors** | Unclear whether responsibility lies with the developer, deployer, platform, oracle, or contracting parties | Complicates redress, compliance, and institutional risk management |
| **Applicable law** | No clear framework for determining governing law in distributed environments | Creates uncertainty in cross-border finance and tokenised markets |
| **Competent forum** | Difficulty identifying the proper court or dispute-resolution body | Weakens predictability and enforceability |
| **Asset location** | Blockchain-based assets may be difficult to localise legally | Complicates restitution, insolvency, and proprietary claims |
| **Proposed responses** | Governing-law clauses, linked legal contracts, arbitration, and hybrid governance | May reduce uncertainty but do not eliminate fragmentation |

## 5. Conclusion

Blockchain and smart contracts are driving a structural transformation in finance, extending beyond payment efficiency towards wider functions of automation, traceability, tokenisation, and trusted digital coordination. However, their potential remains constrained by major technical, legal, and regulatory challenges.

The German case illustrates this dual reality clearly. Blockchain is increasingly viewed not merely as a payment tool, but as a broader trust infrastructure encompassing identity management, certification, and tokenised assets. Yet strong strategic recognition has not translated into widespread implementation, revealing a persistent gap between perceived value and operational adoption.

The analysis also shows that the idea of "code is law" is insufficient for regulated financial markets. Smart contracts may automate execution, but they cannot replace legal interpretation, accountability, and institutional safeguards. Software vulnerabilities, oracle dependence, privacy concerns, scalability limits, liability ambiguity, and cross-border jurisdictional uncertainty all point to the need for a hybrid governance model that combines technological efficiency with legal certainty.

Ultimately, the future of blockchain in finance will depend not on innovation alone, but on the ability to align automation with regulation, standardisation, and institutional trust. In advanced economies such as Germany, the long-term viability of decentralised finance will rest on bridging the gap between technological potential and effective governance. Future policy efforts should therefore focus on regulatory clarity, interoperability standards, data-protection compliance, and institutional readiness to support responsible blockchain adoption in the financial sector.

[44] **Horrach Armo, J. G.** Jurisdiction Agreements in the Field of Smart Contracts and Blockchain Technology. *Revista Electrónica de Estudios Internacionales*, 2021, 42. https://doi.org/10.17103/reei.42.11

[45] **Rodríguez, R. R.** Blockchain and Private International Law. *Revista Electrónica de Estudios Internacionales*, 2022, 43. https://doi.org/10.17103/reei.43.02

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