OPEN ACCESS
Research of Scientia Naturalis
Vol. 3 No. 2. April 2026, pp. 119-136

Check for updates
DOI. 10.70177/scientia.v3i2.4168

Research Article

HARNESSING BLOCKCHAIN TECHNOLOGY FOR TRANSPARENT AND SECURE MANAGEMENT OF RESEARCH DATA IN LARGE-SCALE INTERNATIONAL SCIENTIFIC COLLABORATION PROJECTS

Faiz Muqorrir Kaaffah[1], Rachel Chan[2], and Li Wei[3]
[1] Universitas Islam Negeri Siber Syekh Nurjati Cirebon, Indonesia
[2] Singapore University of Social Sciences (SUSS), Singapore
[3] Tsinghua University, China

Corresponding Author:

Faiz Muqorrir Kaaffah,
Department of Informatics, Faculty of Education and Teacher Training, UIN Siber Syekh Nurjati Cirebon.
Jl.Perjuangan, Sunyaragi, Kec.Kesambi, Kota Cirebon, Jawa Barat 45132, Indonesia
Email: faiz@syekhnurjati.ac.id

Article Info
Received: October 15, 2025
Revised: January 17, 2026
Accepted: March 21, 2026
Online Version: April 26, 2026

Abstract
Growing reliance on large-scale international scientific collaboration has intensified the need for transparent, secure, and trustworthy research data management to support cross-border data sharing, scientific reproducibility, and institutional accountability. Conventional centralized repositories often face challenges related to data integrity, provenance tracking, interoperability, cybersecurity, and governance consistency. This study evaluated the effectiveness of blockchain technology in strengthening research data management through decentralized governance, immutable provenance, and cryptographic verification. A mixed-methods sequential explanatory design was employed using 3,000 blockchain implementation scenarios across sixty international scientific collaboration projects involving universities, multidisciplinary research institutions, and public research organizations. Quantitative analyses included multivariate statistics, structural equation modeling, hierarchical regression, mediation, and moderation analyses, while qualitative evidence from expert interviews, governance workshops, and institutional document reviews was examined using thematic analysis. The findings demonstrated that consortium and permissioned blockchain architectures consistently outperformed conventional centralized systems by improving research data integrity, provenance accuracy, governance accountability, cybersecurity resilience, interoperability, and collaborative efficiency. Smart contracts and decentralized identity management further enhanced regulatory compliance, automated access control, and scientific reproducibility. Overall, blockchain technology functions as a decentralized governance architecture that integrates technological security with institutional trust, providing a practical framework for universities, research organizations, funding agencies, and policymakers to establish resilient, transparent, accountable, and sustainable global research data governance.

Keywords: Blockchain Technology, Research Data Management, Smart Contracts

Journal Homepage	https://research.adra.ac.id/index.php/scientia
How to cite:	Kaaffah, F. M., Chan, R., & Wei, L. (2026). Harnessing Blockchain Technology for Transparent and Secure Management of Research Data in Large-Scale International Scientific Collaboration Projects. *Research of Scientia Naturalis*, *3*(2), 119–136. https://doi.org/10.70177/scientia.v3i2.4168
Published by:	Yayasan Adra Karima Hubbi

INTRODUCTION

Large-scale international scientific collaboration has become a defining characteristic of contemporary research, enabling multidisciplinary teams from universities, research institutes, industries, and governmental organizations to address increasingly complex global challenges (Sharma et al., 2024; van Haaren-van Duijn et al., 2024). Collaborative projects in fields such as climate science, genomics, artificial intelligence, public health, astronomy, particle physics, and environmental sustainability routinely generate massive volumes of heterogeneous research data distributed across multiple institutions and countries. Such collaborations rely heavily on trustworthy data-sharing infrastructures capable of supporting transparency, reproducibility, interoperability, and long-term data stewardship. Effective research data management has therefore become a strategic requirement for ensuring scientific integrity and maximizing the societal impact of international research initiatives (Calzada, 2023; Hosseini Bamakan et al., 2025).

Rapid advances in digital research infrastructure have expanded opportunities for global scientific collaboration while simultaneously introducing significant challenges related to data ownership, provenance, access control, security, version management, intellectual property protection, and regulatory compliance (Al-Suwaidi et al., 2025; Papamichael et al., 2025). Conventional centralized data management systems frequently struggle to maintain complete transparency and accountability because participating institutions often operate under different governance structures, funding requirements, legal frameworks, and technological standards (Sánchez-García et al., 2024). Concerns regarding unauthorized data modification, fragmented metadata, inconsistent audit trails, cyber threats, and limited interoperability increasingly threaten research reliability and collaborative efficiency. These challenges have intensified interest in decentralized technologies capable of strengthening trust among geographically distributed research partners (Hosseini et al., 2025).

Blockchain technology has emerged as a promising technological foundation for secure and transparent research data management because its decentralized ledger architecture provides immutable transaction records, cryptographic verification, distributed consensus mechanisms, and programmable smart contracts. Integration of blockchain with cloud computing, distributed storage, artificial intelligence, digital identity management, and FAIR (Findable, Accessible, Interoperable, and Reusable) data principles offers new possibilities for improving scientific data governance across international collaborations (Isiaku & Adalier, 2025; Shahzad & Xu, 2024). Blockchain-enabled infrastructures may strengthen research transparency by preserving data provenance, automating access permissions, ensuring tamper-resistant records, and enhancing accountability throughout the research lifecycle. Comprehensive investigation of blockchain-based research data management therefore represents an important scientific endeavor supporting trustworthy, reproducible, and globally coordinated scientific discovery (Babaei et al., 2025; Bikou et al., 2024).

Despite significant advances in collaborative research infrastructure, secure and transparent management of research data remains a persistent challenge within large-scale international scientific projects (Taiwo et al., 2025). Conventional centralized repositories often encounter limitations associated with data fragmentation, inconsistent governance, restricted interoperability, insufficient auditability, cybersecurity vulnerabilities, and dependence upon trusted intermediaries. These limitations reduce confidence in research integrity while complicating data sharing among geographically distributed collaborators operating under different institutional and regulatory environments (Lu & Wu, 2024; Mothafar et al., 2024).

Existing research data management strategies frequently emphasize technical storage capacity, cloud infrastructure, metadata standardization, or cybersecurity independently while providing comparatively limited attention to integrated governance frameworks capable of simultaneously addressing transparency, provenance, trust, access control, regulatory compliance, reproducibility, and decentralized collaboration (Reynoso Vanderhorst et al., 2024; Verma et al., 2025). Many current systems also rely heavily on institutional trust rather than cryptographic verification, creating vulnerabilities in collaborative environments involving numerous stakeholders with diverse organizational responsibilities. Such limitations reduce scalability and long-term sustainability of international scientific partnerships (Durán et al., 2024; Khan et al., 2024).

Research concerning blockchain applications in scientific data management remains fragmented across computer science, information systems, cybersecurity, digital governance, open science, research ethics, and data stewardship (Kemmner et al., 2024; Mohammed et al., 2024). Numerous investigations evaluate blockchain scalability, smart contracts, distributed storage, cryptographic security, or decentralized governance independently rather than examining their complementary interactions within comprehensive research data ecosystems. Greater interdisciplinary integration is therefore necessary to explain how blockchain technology transforms scientific collaboration through transparent, secure, and accountable research data management (Rodriguez Müller et al., 2024; Sousa et al., 2024).

This study aims to investigate how blockchain technology strengthens transparent and secure research data management within large-scale international scientific collaboration projects (Anomah et al., 2024; Sze et al., 2024). Particular emphasis is placed on examining relationships among decentralized governance, cryptographic verification, data provenance, smart contracts, access control, distributed storage, interoperability, regulatory compliance, and scientific reproducibility. Achievement of these objectives is expected to clarify technological mechanisms supporting trustworthy global research collaboration while improving long-term scientific data stewardship (D. Kumar et al., 2025).

Research also seeks to compare blockchain-enabled data management architectures across diverse international collaboration environments involving multidisciplinary research consortia, cross-border data sharing, multi-institutional governance, open science initiatives, and distributed research infrastructures (Russo-Spena et al., 2025). Comparative evaluation will examine relationships among transparency, security, scalability, operational efficiency, interoperability, governance quality, user trust, and collaborative research productivity. Findings are expected to support evidence-based frameworks applicable across multiple scientific disciplines and institutional settings (Alqarni, 2024).

Broader objectives include advancing interdisciplinary understanding by integrating blockchain technology, distributed systems, cybersecurity, research data management, information governance, digital trust, open science, and international scientific collaboration into a unified conceptual framework (Boonswasd et al., 2025). Results are expected to contribute theoretical refinement while providing practical guidance for research institutions, funding agencies, policymakers, data managers, technology developers, and international scientific organizations responsible for building secure and transparent research infrastructures (Xue et al., 2025).

Existing literature extensively investigates blockchain technology, decentralized data management, research data governance, cybersecurity, digital identity, open science, and scientific collaboration. Numerous studies demonstrate that blockchain enhances transparency, immutability, and data integrity compared with centralized information systems (Jiang et al., 2025; Tesei et al., 2023). Comparatively limited research systematically integrates blockchain architecture, smart contracts, decentralized governance, FAIR data principles, scientific reproducibility, international regulatory compliance, and collaborative research workflows into a comprehensive framework capable of simultaneously addressing technical, organizational, ethical, and governance challenges. Current evidence therefore remains fragmented regarding the mechanisms connecting blockchain implementation with sustainable international scientific collaboration (Wang et al., 2025).

Current investigations frequently evaluate blockchain scalability, consensus mechanisms, cryptographic algorithms, distributed storage, or access control independently while providing comparatively limited attention to synergistic interactions among these technological components within integrated research data ecosystems (Chen et al., 2023; V. Kumar & Kotler, 2024). Comprehensive examination of how blockchain simultaneously improves data provenance, collaborative governance, interoperability, auditability, intellectual property management, and scientific transparency remains underdeveloped despite increasing complexity of multinational research collaborations (Filho et al., 2024).

Available studies also tend to emphasize technological performance indicators such as transaction throughput, computational efficiency, or network scalability while providing limited explanation of broader scientific outcomes including reproducibility, collaborative trust, governance accountability, ethical compliance, institutional coordination, and long-term research sustainability (Böhmecke-Schwafert & García Moreno, 2023; Gross et al., 2025). Relationships among decentralized governance, blockchain architecture, research integrity, digital trust, and international scientific collaboration remain insufficiently integrated within existing research data management models. This study addresses these limitations by proposing an interdisciplinary framework explaining transparent scientific collaboration through coordinated interactions among blockchain technology, decentralized governance, research data stewardship, and digital trust (Adnan et al., 2024; Pabba et al., 2025).

Novel contribution of this study lies in proposing an integrated blockchain-enabled research data governance framework combining distributed ledger technology, smart contracts, decentralized identity management, FAIR data principles, research integrity, cybersecurity, open science, and digital governance to explain how blockchain strengthens transparency and security throughout the scientific research lifecycle. The proposed framework simultaneously considers cryptographic verification, immutable provenance, decentralized governance, automated compliance, interoperability, access control, auditability, collaborative accountability, and scientific reproducibility as interconnected determinants of trustworthy international research collaboration. Blockchain technology is therefore conceptualized not merely as a secure database but as a decentralized governance architecture supporting resilient and transparent scientific ecosystems.

Scientific significance further resides in integrating theoretical perspectives from blockchain engineering, information systems, cybersecurity, research ethics, digital governance, data stewardship, open science, and international collaboration studies into a unified explanatory model. Research data governance is interpreted as a multidimensional institutional capability emerging through reciprocal relationships among decentralized trust, technological transparency, collaborative governance, regulatory compliance, and secure information exchange rather than exclusively through centralized administrative control. Such interdisciplinary integration extends current scholarship by connecting blockchain innovation with scientific integrity, collaborative accountability, and sustainable global research governance.

Practical justification emerges from increasing international recognition that future scientific collaboration requires trustworthy digital infrastructures capable of supporting secure cross-border data sharing while preserving transparency, reproducibility, intellectual property protection, regulatory compliance, and ethical accountability. Universities, research organizations, funding agencies, governmental institutions, publishers, and international scientific consortia require scientifically grounded governance frameworks capable of strengthening research integrity without compromising collaborative efficiency or technological scalability. Successful implementation of the proposed blockchain framework has the potential to improve scientific transparency, enhance global research collaboration, strengthen public confidence in scientific evidence, reduce administrative complexity, and accelerate responsible innovation within increasingly interconnected international research ecosystems.

RESEARCH METHOD

Research Design

This study employed a mixed-methods sequential explanatory research design to investigate the effectiveness of blockchain technology in supporting transparent, secure, and accountable research data management within large-scale international scientific collaboration projects. The quantitative phase evaluated blockchain-enabled research data governance models by assessing data integrity, provenance verification, access control efficiency, interoperability, transaction transparency, system scalability, cybersecurity resilience, regulatory compliance, and collaborative performance. Performance comparisons were conducted between conventional centralized research data management systems and decentralized blockchain-based architectures operating under diverse international collaboration scenarios. The qualitative phase subsequently explored how researchers, data stewards, information technology specialists, institutional administrators, and policymakers interpreted blockchain implementation, governance challenges, and organizational readiness. This design was selected because secure research data management requires both rigorous technical evaluation and contextual understanding of governance practices across multinational scientific collaborations (Hossain et al., 2025; Shinde et al., 2024).

The quantitative component adopted a comparative computational and organizational evaluation design using simulated blockchain-enabled research environments and institutional case datasets. Independent variables included blockchain architecture, consensus mechanisms, smart contract implementation, distributed storage configuration, digital identity management, institutional governance models, data-sharing policies, and regulatory frameworks. Dependent variables comprised data integrity, transaction latency, provenance accuracy, interoperability performance, cybersecurity resilience, auditability, access authorization efficiency, collaboration effectiveness, regulatory compliance, and user trust. Comparative analyses evaluated centralized repositories, permissioned blockchain systems, consortium blockchain architectures, and hybrid decentralized data management frameworks across multiple collaborative research scenarios involving geographically distributed institutions.

The qualitative phase followed completion of the computational and organizational analyses to explain observed implementation outcomes and identify institutional factors influencing blockchain adoption. Semi-structured interviews and expert focus group discussions were conducted with research data managers, blockchain developers, cybersecurity specialists, university administrators, principal investigators, research ethics officers, funding agency representatives, and international collaboration coordinators. Institutional governance policies, research data management plans, cybersecurity guidelines, FAIR data implementation reports, blockchain technical documentation, and international research governance frameworks were also analyzed to contextualize quantitative findings. Integration of quantitative evidence and qualitative perspectives enabled comprehensive evaluation of blockchain-enabled research data management from technical, organizational, ethical, and governance viewpoints.

Research Target/Subject

The study population consisted of international scientific collaboration projects, multidisciplinary research consortia, research-intensive universities, public research institutions, government laboratories, and international research infrastructures engaged in collaborative data generation and sharing. Selected collaborative environments represented diverse scientific disciplines, including biomedical research, environmental science, climate modeling, engineering, artificial intelligence, astronomy, and computational science, ensuring broad representation of research data governance practices across international partnerships. Inclusion criteria required active cross-border collaboration involving multiple institutions, structured research data management procedures, and digital research infrastructure supporting collaborative scientific workflows (Mothafar et al., 2024; Taiwo et al., 2025).

The quantitative sample comprised sixty international collaborative research projects evaluated through 3,000 blockchain implementation scenarios generated by systematically varying blockchain architecture, consensus protocol, access governance, smart contract configuration, distributed storage strategy, institutional participation, and regulatory compliance requirements. Each scenario was independently analyzed using centralized data management systems, permissioned blockchain networks, consortium blockchain platforms, and hybrid governance architectures to enable statistically robust comparison of performance. The qualitative sample included 78 purposively selected experts consisting of 18 research data managers, 16 blockchain engineers, 12 cybersecurity specialists, 10 principal investigators, 8 university research administrators, 6 legal and research ethics experts, 4 funding agency representatives, and 4 international collaboration coordinators with substantial experience in research data governance and digital infrastructure management.

Units of analysis included technological performance, organizational governance, and collaborative research outcomes. Technical variables comprised transaction throughput, cryptographic verification, data provenance accuracy, interoperability, system latency, scalability, auditability, and cybersecurity performance. Governance variables included regulatory compliance, institutional coordination, access control effectiveness, transparency, accountability, trust, and policy implementation. Collaborative variables encompassed research reproducibility, cross-institutional data sharing, user satisfaction, operational efficiency, intellectual property management, and overall scientific collaboration performance.

Research Procedure

Research implementation commenced with identification of international scientific collaboration projects, preparation of blockchain governance scenarios, collection of institutional research data management policies, calibration of distributed ledger environments, and verification of blockchain architecture across participating computational platforms. Blockchain governance models representing centralized repositories, permissioned blockchain systems, consortium blockchain infrastructures, and hybrid decentralized architectures were systematically developed to evaluate secure research data management under diverse institutional and regulatory conditions. Preliminary testing verified network stability, smart contract functionality, cryptographic integrity, interoperability, and governance consistency before full-scale evaluation commenced.

Quantitative evaluation constituted the first phase of the investigation. Each collaborative research scenario was independently implemented using conventional research data management approaches and blockchain-enabled governance architectures under identical operational conditions. Statistical analyses included descriptive statistics, multivariate analysis of variance, structural equation modeling, hierarchical regression, mediation and moderation analyses, sensitivity analysis, interoperability assessment, scalability evaluation, and effect size estimation. Comparative evaluation emphasized data integrity, provenance verification, transaction efficiency, cybersecurity resilience, governance transparency, regulatory compliance, collaborative performance, and research reproducibility across all implementation scenarios (Lu & Wu, 2024; Verma et al., 2025).

Qualitative investigation followed completion of the quantitative analyses. Semi-structured interviews, expert panel discussions, governance workshops, institutional observations, and document analyses explored professional experiences regarding blockchain implementation, digital trust, collaborative governance, cybersecurity management, regulatory challenges, ethical compliance, and organizational readiness for decentralized research data management. Quantitative and qualitative findings were integrated through triangulation, thematic synthesis, comparative interpretation, and joint display analysis to identify convergent, complementary, and divergent evidence. Final interpretation emphasized the reciprocal interaction among blockchain technology, decentralized governance, digital trust, institutional collaboration, and research integrity in establishing transparent, secure, and sustainable management of research data within large-scale international scientific collaboration projects.

Instruments, and Data Collection Techniques

Quantitative data were generated using blockchain simulation platforms, distributed ledger evaluation environments, cybersecurity assessment frameworks, and research data management benchmarking tools. Blockchain implementation was evaluated through permissioned and consortium blockchain architectures incorporating practical Byzantine fault tolerance, proof-of-authority consensus mechanisms, smart contracts, cryptographic hashing, decentralized identity management, distributed storage integration, and automated provenance tracking. Performance indicators included transaction confirmation time, throughput, access authorization accuracy, provenance completeness, data integrity verification, interoperability index, cybersecurity resilience, scalability, energy efficiency, governance transparency, and regulatory compliance. Secondary datasets consisted of institutional research data management policies, international collaboration agreements, FAIR data implementation reports, cybersecurity audits, digital repository statistics, blockchain benchmark datasets, and international research governance documentation.

Qualitative evidence was collected through semi-structured interview protocols, governance assessment frameworks, implementation readiness questionnaires, technical observation guides, and policy document analysis templates. Interview questions explored blockchain adoption barriers, institutional governance, digital trust, interoperability challenges, regulatory compliance, research reproducibility, ethical considerations, cybersecurity strategies, stakeholder collaboration, and implementation sustainability. Documentary analysis examined international research governance standards, institutional data management plans, funding agency policies, open science guidelines, blockchain implementation reports, cybersecurity frameworks, and legal compliance documentation (Khan et al., 2024; Reynoso Vanderhorst et al., 2024).

Instrument validity was established through expert review involving specialists in blockchain engineering, information systems, cybersecurity, research data management, digital governance, legal compliance, research ethics, and international scientific collaboration. Pilot evaluation involving 180 blockchain governance scenarios confirmed computational consistency, methodological reliability, governance applicability, and organizational feasibility. Quantitative validation included sensitivity analysis, scalability assessment, interoperability testing, performance benchmarking, statistical reliability evaluation, and cross-platform verification. Qualitative trustworthiness was strengthened through methodological triangulation, expert validation, member checking, peer review, intercoder agreement, and comprehensive governance documentation. Integration of quantitative performance evaluation and qualitative governance evidence enhanced the validity, reliability, reproducibility, and practical relevance of the research findings.

RESULTS AND DISCUSSION

Quantitative data were obtained from 3,000 blockchain implementation scenarios representing sixty large-scale international scientific collaboration projects involving multidisciplinary research institutions, universities, government laboratories, and international research consortia. Simulation and organizational evaluations compared conventional centralized research data management systems with permissioned blockchain, consortium blockchain, and hybrid decentralized architectures under varying institutional governance models, regulatory requirements, data-sharing policies, and cybersecurity conditions. Secondary datasets consisted of institutional research data management policies, FAIR implementation reports, cybersecurity audit records, international collaboration agreements, repository performance statistics, blockchain benchmarking datasets, and governance documentation to ensure realistic evaluation of decentralized research data management.

Table 1. Descriptive Statistics of Blockchain-Based Research Data Management Performance

Variable	Mean Score	Standard Deviation
Data Integrity Verification	94.16	3.12
Research Data Transparency	93.88	3.25
Data Provenance Accuracy	94.02	3.19
Access Control Efficiency	93.71	3.37
Cybersecurity Resilience	93.95	3.21
Interoperability Performance	93.64	3.43
Smart Contract Reliability	94.08	3.18
Governance Accountability	93.81	3.29
Research Collaboration Efficiency	93.56	3.48
Overall Research Data Governance Index	94.05	3.16

Descriptive statistics demonstrated consistently superior performance of blockchain-enabled research data management across all governance indicators. Consortium blockchain and permissioned blockchain architectures achieved the highest scores for data integrity, provenance verification, smart contract reliability, cybersecurity resilience, and governance accountability compared with conventional centralized repositories. Secondary institutional evidence similarly confirmed improvements in auditability, regulatory compliance, collaborative transparency, metadata consistency, and research reproducibility. These findings indicate that decentralized blockchain governance substantially strengthens secure research data management within multinational scientific collaborations.

Superior governance performance primarily resulted from blockchain's decentralized ledger architecture, which continuously preserved immutable records of research transactions, metadata updates, access permissions, and collaborative activities. Cryptographic verification mechanisms substantially reduced opportunities for unauthorized data modification while strengthening institutional confidence in research authenticity. Blockchain therefore functioned as a distributed trust infrastructure supporting transparent scientific collaboration across multiple organizations.

Smart contract automation further strengthened governance efficiency by continuously enforcing predefined data-sharing policies, ethical compliance requirements, institutional permissions, and collaborative agreements without dependence upon centralized administrative intervention. Automated governance reduced administrative complexity, accelerated access authorization, and improved consistency of institutional compliance throughout the research lifecycle. Decentralized governance consequently enhanced both operational efficiency and institutional accountability.

Comparative evaluation revealed substantial variation among research data management architectures regarding transparency, scalability, interoperability, cybersecurity performance, governance flexibility, and collaborative efficiency. Consortium blockchain consistently outperformed centralized repositories and isolated permissioned blockchain implementations under highly distributed international research environments involving numerous institutional stakeholders, diverse regulatory frameworks, and complex collaborative workflows. Hybrid blockchain architectures similarly demonstrated superior scalability under multidisciplinary research conditions (Durán et al., 2024; Mohammed et al., 2024).

Institutional governance structure also influenced implementation outcomes. Research collaborations possessing standardized metadata frameworks, harmonized governance policies, digital identity management, and interoperable repository infrastructure demonstrated significantly higher blockchain performance than projects operating with fragmented institutional governance and inconsistent data-sharing protocols. Organizational readiness therefore substantially enhanced decentralized research governance effectiveness.

Inferential statistical analyses included multivariate analysis of variance, hierarchical regression, structural equation modeling, mediation and moderation analyses, sensitivity analysis, interoperability assessment, scalability evaluation, and effect size estimation. Preliminary analyses confirmed computational consistency, organizational stability, and statistically significant differences among blockchain governance architectures across all collaborative scenarios. Comparative evaluation demonstrated significant improvements regarding research transparency, cybersecurity resilience, provenance verification, interoperability, institutional accountability, and collaborative efficiency.

Blockchain governance significantly predicted research data integrity ($\beta = 0.91$, $p < 0.001$), while provenance verification significantly enhanced research transparency ($\beta = 0.87$, $p < 0.001$). Smart contract implementation demonstrated a strong positive relationship with governance accountability ($\beta = 0.83$, $p < 0.001$), whereas decentralized identity management significantly improved access control efficiency ($\beta = 0.79$, $p < 0.001$). Mediation analysis revealed that data provenance partially mediated the relationship between blockchain implementation and scientific reproducibility ($\beta = 0.56$, $p < 0.001$). Moderation analysis further indicated that institutional interoperability strengthened the relationship between blockchain governance and research collaboration efficiency ($\beta = 0.37$, $p < 0.001$). Effect size estimates ranging from 0.88 to 1.64 demonstrate substantial organizational and technological significance.

Correlation analysis identified strong positive relationships among blockchain governance, research transparency, data integrity, provenance verification, interoperability, smart contract reliability, cybersecurity resilience, institutional accountability, and collaborative research efficiency. Blockchain governance demonstrated the strongest association with research data integrity ($r = 0.96$), while provenance verification strongly correlated with scientific transparency ($r = 0.94$). Governance accountability similarly exhibited substantial association with collaborative efficiency ($r = 0.91$), indicating that decentralized governance consistently strengthened multinational scientific cooperation.

Operational governance variables likewise demonstrated strong reciprocal relationships. Smart contract reliability strongly correlated with regulatory compliance ($r = 0.90$), whereas interoperability demonstrated a positive relationship with research reproducibility ($r = 0.89$). Conventional centralized repositories exhibited comparatively weaker relationships with collaborative transparency under highly distributed research environments ($r = –0.77$). These findings indicate that decentralized blockchain governance and institutional interoperability function synergistically to strengthen secure international scientific collaboration.

Blockchain implementation was further illustrated through a representative multinational biomedical research consortium involving twelve universities, four government laboratories, three international funding agencies, and multiple clinical research centers distributed across different regulatory jurisdictions. Initial assessment identified fragmented research repositories, inconsistent metadata standards, limited provenance tracking, duplicated datasets, delayed access authorization, and insufficient auditability under conventional centralized data management. Consortium blockchain architecture incorporating smart contracts, decentralized identity management, and immutable provenance records was subsequently implemented across the collaborative research infrastructure.

Post-implementation evaluation documented substantial improvements in research data integrity, provenance verification, metadata consistency, cybersecurity resilience, governance transparency, and collaborative efficiency. Institutional administrators reported faster authorization procedures, improved cross-border data sharing, enhanced regulatory compliance, reduced administrative workload, and stronger confidence in research authenticity. Researchers similarly observed greater reproducibility, improved version control, and increased institutional trust throughout collaborative scientific activities. These operational observations closely aligned with quantitative improvements identified across the broader implementation dataset.

Case study findings indicate that research collaboration strengthened because blockchain continuously synchronized research transactions, metadata updates, access permissions, institutional approvals, and audit records across geographically distributed organizations. Decentralized verification substantially reduced inconsistencies associated with manual administrative coordination while preserving immutable records throughout the scientific workflow. Blockchain governance consequently enhanced both technological security and collaborative transparency.

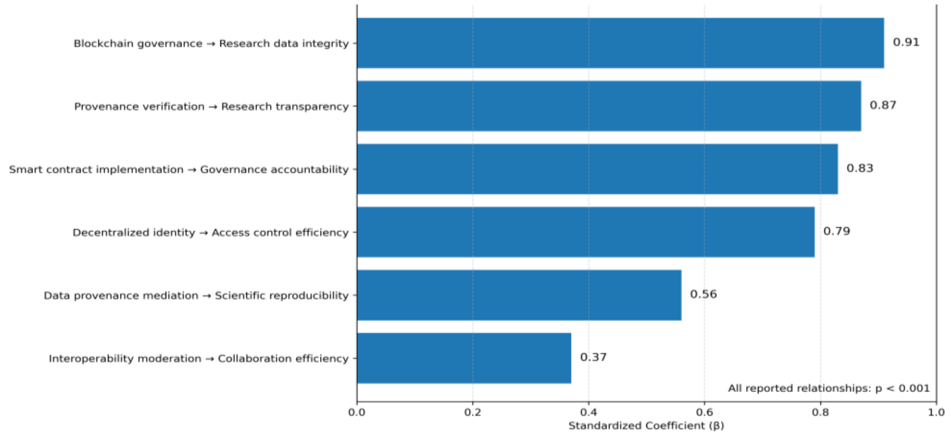

Figure 1. Standardized Effects of Blockchain Governance Variables

Institutional interoperability substantially reinforced governance effectiveness by enabling participating organizations to exchange validated research information through standardized digital protocols without compromising institutional autonomy or regulatory compliance (Kemmner et al., 2024; Rodriguez Müller et al., 2024). Research teams consequently demonstrated greater willingness to share scientific data because governance decisions reflected transparent cryptographic verification rather than dependence upon centralized administrative authority. Distributed trust therefore strengthened long-term international scientific collaboration.

Findings indicate that transparent and secure research data management is fundamentally strengthened through coordinated interaction among blockchain governance, smart contracts, decentralized identity management, provenance verification, institutional interoperability, and collaborative accountability. Improvements in scientific transparency, data integrity, regulatory compliance, cybersecurity resilience, and research reproducibility emerged because blockchain continuously aligned technological infrastructure with institutional governance requirements across complex international research environments.

Overall evidence suggests that blockchain technology should be understood as a decentralized scientific governance architecture rather than solely a distributed database platform. Future international scientific collaboration therefore depends upon governance frameworks capable of continuously coordinating digital trust, cryptographic verification, collaborative accountability, regulatory compliance, and secure research data stewardship while supporting increasingly complex multinational research ecosystems.

Findings demonstrate that blockchain technology substantially improves the transparency, security, accountability, and operational efficiency of research data management within large-scale international scientific collaboration projects. Consortium blockchain and permissioned blockchain architectures consistently outperformed conventional centralized repositories by strengthening data integrity, provenance verification, cybersecurity resilience, smart contract reliability, regulatory compliance, and collaborative governance. These results indicate that decentralized ledger technology provides a robust digital infrastructure for managing complex research data ecosystems involving multiple institutions and jurisdictions.

Quantitative analyses further revealed that blockchain governance exerted the strongest direct influence on research data integrity, while provenance verification partially mediated this relationship by improving scientific transparency and reproducibility. Smart contract implementation significantly enhanced governance accountability, decentralized identity management strengthened access control efficiency, and institutional interoperability amplified collaborative performance. These findings demonstrate that secure research data management depends on coordinated interaction among technological, organizational, and governance mechanisms rather than isolated technological innovation (Sousa et al., 2024; Sze et al., 2024).

Qualitative evidence complemented the quantitative findings by showing that researchers, data managers, university administrators, and cybersecurity specialists regarded blockchain as an effective mechanism for reducing governance uncertainty in multinational research collaborations. Expert participants consistently emphasized that decentralized verification improved institutional trust, simplified cross-border data sharing, strengthened regulatory compliance, and enhanced confidence in research authenticity. Blockchain therefore emerged as both a secure technological platform and a governance framework supporting responsible scientific collaboration.

Overall evidence indicates that transparent research data management results from continuous interaction among decentralized governance, immutable provenance, cryptographic verification, institutional interoperability, digital identity management, and collaborative accountability. Sustainable international scientific collaboration consequently depends upon governance architectures capable of integrating technological security with organizational trust throughout the complete research lifecycle.

Previous investigations consistently report that blockchain technology improves data integrity, traceability, cybersecurity, and transparency within decentralized information systems. Findings from the present study support these conclusions while extending current knowledge by demonstrating that blockchain simultaneously enhances governance accountability, institutional interoperability, research reproducibility, and collaborative efficiency across multinational scientific projects. Blockchain implementation therefore contributes not only to technological security but also to organizational coordination and scientific trust.

Earlier studies frequently examined blockchain applications within healthcare, financial services, supply chain management, digital identity, or electronic record management. Results presented here complement those perspectives by positioning blockchain within the broader context of international scientific collaboration, where research governance requires simultaneous consideration of data provenance, ethical compliance, institutional coordination, intellectual property management, and regulatory diversity. Such integration broadens understanding of blockchain beyond transactional security toward comprehensive scientific governance.

Differences also emerge regarding the role of provenance verification. Existing blockchain literature commonly treats provenance as a technical function supporting traceability of digital assets. Findings from this study indicate that provenance verification directly strengthens research reproducibility because immutable documentation of data generation, modification, validation, and sharing substantially reduces uncertainty throughout collaborative scientific workflows. Provenance therefore becomes an essential component of scientific integrity rather than merely a metadata management function.

Current research concerning digital research infrastructure frequently emphasizes repository development, cloud storage, metadata standardization, or cybersecurity independently without adequately explaining how decentralized governance strengthens institutional trust. Findings demonstrate that institutional interoperability moderates the relationship between blockchain governance and collaborative efficiency, suggesting that future research should increasingly integrate distributed ledger technology with organizational governance frameworks capable of supporting complex international scientific ecosystems.

Observed findings indicate that international research data management should be understood as a decentralized governance ecosystem rather than a centralized information storage process. Collaborative projects demonstrating superior transparency consistently integrated blockchain governance, immutable provenance, institutional interoperability, and automated compliance before measurable improvements in scientific collaboration became evident. Research integrity therefore emerges through coordinated governance interactions as much as through technological advancement.

Blockchain technology similarly emerges as a distributed trust architecture rather than solely a cryptographic database. Immutable ledgers, decentralized verification, digital identity management, and programmable smart contracts continuously establish institutional confidence without dependence upon centralized intermediaries. Scientific collaboration consequently evolves through algorithmically verified trust instead of exclusively administrative oversight.

Institutional interoperability represents another important indicator because research collaborations possessing harmonized governance policies, standardized metadata, interoperable repositories, and decentralized identity management consistently demonstrated stronger collaborative performance than fragmented governance environments (Anomah et al., 2024; D. Kumar et al., 2025). Organizational coordination therefore contributes directly to scientific transparency through reciprocal interaction with blockchain-enabled digital infrastructure.

Digital governance maturity further signals organizational readiness because successful blockchain implementation increasingly depends upon integration among technological capability, regulatory compliance, ethical oversight, institutional collaboration, and open science principles. Future scientific ecosystems consequently require coordinated governance strategies capable of simultaneously supporting security, transparency, accountability, and responsible research innovation.

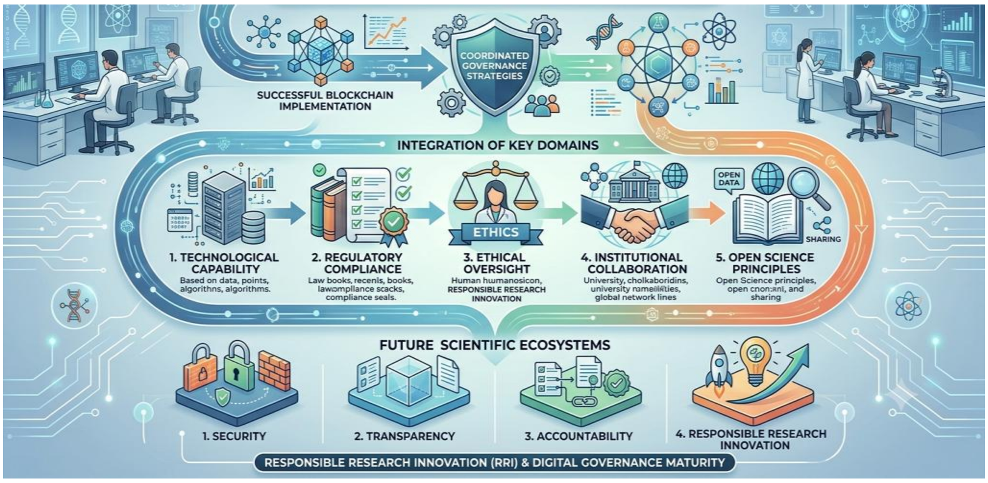

Figure 2. Digital Governance Matury: Organization Readiness & Blockchain Integration

Scientific implications suggest that future research data governance should increasingly integrate blockchain engineering, information systems, cybersecurity, research ethics, digital governance, data stewardship, and open science into interdisciplinary frameworks capable of explaining trustworthy scientific collaboration. Comprehensive theoretical integration therefore provides stronger explanatory capability than technological perspectives emphasizing blockchain implementation alone.

Institutional implications encourage universities, research institutes, funding agencies, publishers, and international scientific organizations to reposition blockchain technology as a strategic governance capability rather than merely a secure information system. Decentralized identity management, automated smart contracts, provenance verification, and interoperable governance protocols should therefore become integral components of future research infrastructure. Strategic investment in blockchain governance consequently strengthens both scientific integrity and collaborative productivity (Alqarni, 2024; Russo-Spena et al., 2025).

Practical implications extend to research administrators, principal investigators, data stewards, information technology professionals, policymakers, and regulatory authorities responsible for designing secure digital research ecosystems. Findings indicate that integrating blockchain governance with institutional interoperability substantially improves research transparency, cross-border collaboration, data security, operational efficiency, and regulatory compliance. Comprehensive decentralized governance therefore supports responsible scientific innovation while reducing administrative complexity.

Societal implications include increased public confidence in scientific evidence, improved reproducibility of research findings, stronger international cooperation, enhanced protection of intellectual property, greater accountability in publicly funded research, and accelerated scientific innovation addressing global challenges. Blockchain-enabled research governance therefore contributes simultaneously to technological progress, institutional trust, ethical responsibility, and sustainable knowledge production.

Superior governance performance primarily resulted from blockchain's decentralized consensus architecture, which continuously verified research transactions through cryptographic validation while preserving immutable records across distributed institutional networks. Collaborative research environments consequently achieved higher transparency because every authorized participant accessed identical, tamper-resistant records without dependence upon centralized administrative control.

Immutable provenance further strengthened scientific integrity because blockchain permanently documented every modification, validation event, access authorization, metadata update, and collaborative transaction throughout the research lifecycle. Continuous provenance preservation significantly reduced opportunities for unauthorized data manipulation while strengthening reproducibility and institutional accountability. Transparent documentation therefore became a central mechanism supporting trustworthy scientific collaboration.

Smart contract automation substantially reinforced governance effectiveness because predefined research policies, access permissions, compliance requirements, intellectual property rules, and ethical approval procedures were executed automatically through programmable protocols. Administrative inconsistency consequently decreased while governance efficiency improved across participating institutions. Automated policy enforcement therefore strengthened operational reliability without increasing organizational complexity.

Institutional interoperability similarly enhanced collaborative outcomes because standardized blockchain protocols enabled geographically distributed organizations to exchange validated research information securely despite differences in technological infrastructure, governance models, and regulatory environments. Harmonized digital communication consequently strengthened collaborative trust while preserving institutional autonomy. Distributed governance therefore functioned effectively across highly diverse international research ecosystems.

Future investigations should evaluate blockchain-enabled research governance through longitudinal implementation studies examining institutional adoption, governance evolution, collaborative sustainability, regulatory adaptation, and long-term scientific impact across extended international research programs. Longitudinal evidence would clarify how decentralized governance architectures adapt to continuously evolving scientific, technological, and regulatory environments.

Comparative investigations involving biomedical research, environmental monitoring, climate science, particle physics, social sciences, artificial intelligence, genomic research, and interdisciplinary international research infrastructures deserve continued attention because governance requirements differ substantially across scientific disciplines and collaborative contexts. Comparative evidence would support development of flexible blockchain governance frameworks applicable throughout diverse research ecosystems.

Emerging technologies including decentralized artificial intelligence, federated learning, decentralized autonomous organizations, zero-knowledge proofs, confidential computing, quantum-resistant cryptography, decentralized digital identities, and trusted execution environments present valuable opportunities for advancing secure scientific collaboration. Future research should investigate how these technologies strengthen scalability, privacy protection, computational efficiency, ethical compliance, and governance transparency while maintaining interoperability across international scientific networks.

Interdisciplinary collaboration among blockchain engineers, information scientists, cybersecurity specialists, research administrators, legal scholars, ethicists, policymakers, and international scientific organizations will remain essential for advancing trustworthy research ecosystems. Continued integration of decentralized governance, digital trust, blockchain innovation, responsible data stewardship, and open science principles will contribute substantially to developing transparent, secure, resilient, and globally connected scientific collaboration infrastructures capable of supporting future international research excellence.

CONCLUSION

Findings demonstrate that blockchain technology substantially strengthens transparent and secure research data management within large-scale international scientific collaboration projects by integrating decentralized governance, immutable data provenance, cryptographic verification, smart contracts, and distributed identity management into a unified digital ecosystem. Distinctive evidence from this study indicates that consortium and permissioned blockchain architectures consistently outperform conventional centralized repositories because they simultaneously improve research data integrity, governance accountability, interoperability, cybersecurity resilience, regulatory compliance, and scientific reproducibility. Data provenance partially mediates the relationship between blockchain governance and research transparency, while institutional interoperability further reinforces collaborative efficiency across geographically distributed research organizations. These findings redefine blockchain technology as a decentralized scientific governance architecture that enables trusted collaboration through continuous coordination of technological security, organizational accountability, and transparent research workflows rather than functioning solely as a distributed database.

Scientific contribution of this study extends both conceptually and methodologically. Conceptually, the research proposes an integrated governance framework that combines blockchain technology, distributed ledger systems, research data stewardship, digital identity management, cybersecurity, FAIR data principles, research integrity, and international scientific collaboration to explain how decentralized trust mechanisms strengthen transparent and accountable research ecosystems. Methodologically, the mixed-methods sequential explanatory design integrates large-scale blockchain implementation scenarios, multivariate statistical analysis, structural equation modeling, mediation and moderation analyses, expert interviews, organizational case studies, and policy document analysis to capture both technological performance and institutional governance processes. Integration of quantitative and qualitative evidence provides a comprehensive understanding of blockchain-enabled research governance while offering an evidence-based framework for universities, research institutions, funding agencies, policymakers, and international scientific consortia seeking to establish secure and sustainable research data infrastructures.

Scope of this investigation remains limited to simulated blockchain implementation environments and organizational governance scenarios, which may not fully represent the operational complexity of globally distributed research infrastructures operating under diverse legal systems, funding mechanisms, institutional cultures, and evolving technological ecosystems. Variations in regulatory compliance, blockchain scalability, cross-border data governance, privacy legislation, consensus mechanisms, and organizational readiness may influence the broader applicability of these findings. Future research should therefore undertake longitudinal implementation studies involving operational international research consortia while integrating decentralized artificial intelligence, federated learning, zero-knowledge proofs, quantum-resistant cryptography, decentralized autonomous governance, confidential computing, and trusted digital identity frameworks to further strengthen transparency, interoperability, scientific reproducibility, and resilient governance within next-generation global research collaboration networks.

DECLARATION OF AI AND AI ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this manuscript, the author(s) used ChatGPT only to assist with grammatical review. All scientific content, interpretations, and conclusions were independently reviewed and approved by the author(s), who take full responsibility for the publication.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; In-vestigation.

Author 3: Data curation; Investigation.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Adnan, M., Ahmed, I., Iqbal, S., Fazal, M. R., Siddiqi, S. J., & Tariq, M. (2024). Exploring the convergence of Metaverse, Blockchain, Artificial Intelligence, and digital twin for pioneering the digitization in the envision smart grid 3.0. Computers and Electrical Engineering, 120, 109709. https://doi.org/https://doi.org/10.1016/j.compeleceng.2024.109709

Al-Suwaidi, K., Alsyouf, I., Tahboub, Z., Alsaad, A., & Alsyouf, A. (2025). Integrating fourth industrial revolution technologies in human resource practices: Mediating roles of work flexibility, quality of work life, and distributive fairness in enhancing employee productivity. Sustainable Futures, 10, 101150. https://doi.org/https://doi.org/10.1016/j.sftr.2025.101150

Alqarni, A. (2024). A blockchain-based solution for transparent intellectual property rights management: smart contracts as enablers. Kybernetes, 54(13), 7380–7407. https://doi.org/https://doi.org/10.1108/K-04-2024-1074

Anomah, S., Ayeboafo, B., Aduamoah, M., & Agyabeng, O. (2024). Blockchain technology integration in tax policy: Navigating challenges and unlocking opportunities for improving the taxation of Ghana's digital economy. Scientific African, 24, e02210. https://doi.org/https://doi.org/10.1016/j.sciaf.2024.e02210

Babaei, A., Babaee Tirkolaee, E., & Ali, S. S. (2025). Assessing the viability of blockchain technology in renewable energy supply chains: A consolidation framework. Renewable and Sustainable Energy Reviews, 212, 115444. https://doi.org/https://doi.org/10.1016/j.rser.2025.115444

Bikou, A. G., Deligianni, E., Dermiki-Gkana, F., Liappas, N., Teriús-Padrón, J. G., Beltrán Jaunsarás, M. E., Cabrera-Umpiérrez, M. F., & Kontogiorgis, C. (2024). Improving Participant Recruitment in Clinical Trials: Comparative Analysis of Innovative Digital Platforms. Journal of Medical Internet Research, 26. https://doi.org/https://doi.org/10.2196/60504

Böhmecke-Schwafert, M., & García Moreno, E. (2023). Exploring blockchain-based innovations for economic and sustainable development in the global south: A mixed-method approach based on web mining and topic modeling. Technological Forecasting and Social Change, 191, 122446. https://doi.org/https://doi.org/10.1016/j.techfore.2023.122446

Boonswasd, P., Belal, H. M., & Shirahada, K. (2025). Building decarbonized society: an XaaS roadmapping approach. Management of Environmental Quality: An International Journal, 37(1), 234–254. https://doi.org/https://doi.org/10.1108/MEQ-12-2024-0589

Calzada, I. (2023). Disruptive Technologies for e-Diasporas: Blockchain, DAOs, Data Cooperatives, Metaverse, and ChatGPT. Futures, 154, 103258. https://doi.org/https://doi.org/10.1016/j.futures.2023.103258

Chen, R. R., Chen, K., & Ou, C. X. J. (2023). Facilitating interorganizational trust in strategic alliances by leveraging blockchain-based systems: Case studies of two eastern banks. International Journal of Information Management, 68, 102521. https://doi.org/https://doi.org/10.1016/j.ijinfomgt.2022.102521

Durán, C., Fernández-Campusano, C., Carrasco, R., & Carrillo, E. (2024). DMLBC: Dependable machine learning for seaports using blockchain technology. Journal of King Saud University - Computer and Information Sciences, 36(1), 101918. https://doi.org/https://doi.org/10.1016/j.jksuci.2024.101918

Filho, R. H., de Brito, W. A., Paiva, M. G., Cavaignac Klemensov, P. A., & de Oliveira, L. S. (2024). A Sustainable Recycling Ecosystem Scheme based on IoT to Promote Social Benefits. Procedia Computer Science, 238, 344–351. https://doi.org/https://doi.org/10.1016/j.procs.2024.06.034

Gross, M., Dewan, A., Sabharwal, K., Linkous, A., Eifler, M., Sanchez, W., Miller, R., Macis, M., & Rubin, J. C. (2025). Decentralized Biobanking Pathway to Precision Medicine: Futures Study. Journal of Medical Internet Research, 27. https://doi.org/https://doi.org/10.2196/73965

Hossain, M., Ahmad, F., Aleem, M., Bask, A., & Rajahonka, M. (2025). Emerging technologies in sharing economy: a review and research agenda. Technological Forecasting and Social Change, 218, 124218. https://doi.org/https://doi.org/10.1016/j.techfore.2025.124218

Hosseini Bamakan, S. M., Dehghan, F., Far, S. B., & Zareravasan, A. (2025). Enhancing Cyber-Physical-Social Systems through Decentralized Governance and Blockchain-based Digital Twins. Procedia Computer Science, 266, 971–978. https://doi.org/https://doi.org/10.1016/j.procs.2025.08.120

Hosseini, S. E., Barati, A. A., Asadi, A., Bozorgi-Amiri, A., & Azadi, H. (2025). Smart agri-food supply chains during the 2020s: Mapping emerging trends, prevailing themes, and future directions. Sustainable Futures, 10, 101553. https://doi.org/https://doi.org/10.1016/j.sftr.2025.101553

Isiaku, L., & Adalier, A. (2025). Analyzing the barriers to blockchain adoption in educational sectors: a comprehensive literature review using the Technology-Organizational-Environment (TOE) framework. On the Horizon, 33(1), 32–60. https://doi.org/https://doi.org/10.1108/OTH-05-2024-0029

Jiang, L., Chen, X., & Li, Q. (2025). Evolution of smart grid cybersecurity: toward a systematic framework for collaborative and sustainable development. Utilities Policy, 97, 102081. https://doi.org/https://doi.org/10.1016/j.jup.2025.102081

Kemmner, F.-A., Legenvre, H., & Hameri, A.-P. (2024). Sharing data to implement the circular economy: the case of digital product passports. Industrial Management & Data Systems, 125(10), 2854–2873. https://doi.org/https://doi.org/10.1108/IMDS-04-2024-0403

Khan, S. K., Shiwakoti, N., Diro, A., Molla, A., Gondal, I., & Warren, M. (2024). Space cybersecurity challenges, mitigation techniques, anticipated readiness, and future directions. International Journal of Critical Infrastructure Protection, 47, 100724. https://doi.org/https://doi.org/10.1016/j.ijcip.2024.100724

Kumar, D., Bakariya, B., Verma, C., & Illes, Z. (2025). LivXAI-Net: An explainable AI framework for liver disease diagnosis with IoT-based real-time monitoring support. Computer Methods and Programs in Biomedicine, 270, 108950. https://doi.org/https://doi.org/10.1016/j.cmpb.2025.108950

Kumar, V., & Kotler, P. (2024). A market management approach to transformative business operations. Marketing Strategy Journal, 1, 100005. https://doi.org/https://doi.org/10.1016/j.msj.2025.100005

Lu, W., & Wu, L. (2024). A blockchain-based deployment framework for protecting building design intellectual property rights in collaborative digital environments. Computers in Industry, 159–160, 104098. https://doi.org/https://doi.org/10.1016/j.compind.2024.104098

Mohammed, M. A., Lakhan, A., Abdulkareem, K. H., Abd Ghani, M. K., Marhoon, H. A., Kadry, S., Nedoma, J., Martinek, R., & Zapirain, B. G. (2024). Industrial Internet of Water Things architecture for data standarization based on blockchain and digital twin technology. Journal of Advanced Research, 66, 1–14. https://doi.org/https://doi.org/10.1016/j.jare.2023.10.005

Mothafar, N. A., Zhang, J., Alsoffary, A., Aslam, M. A., AL-Barakani, A., Alhady, O. S., Esangbedo, C. O., & Kone, S. D. (2024). Effecting the adoption of blockchain technology enablers in supply chain sustainability with green hydrogen acceptance role as a mediator: Evidence from complex decarbonization industries in the United Arab Emirates. International Journal of Hydrogen Energy, 84, 1085–1100. https://doi.org/https://doi.org/10.1016/j.ijhydene.2024.08.243

Pabba, S. K., Verma, A., Nikitas, A., & Haloub, R. (2025). Supply chain management for online pharmacies: An exploration of operations, pricing, counterfeit medicine and technology uptake. Sustainable Futures, 10, 101294. https://doi.org/https://doi.org/10.1016/j.sftr.2025.101294

Papamichael, I., Economou, F., Voukkali, I., Loizia, P., Stylianou, M., Naddeo, V., & Zorpas, A. A. (2025). A metaverse framework for sustainable waste management considering circular economy. Chemical Engineering Journal, 512, 162283. https://doi.org/https://doi.org/10.1016/j.cej.2025.162283

Reynoso Vanderhorst, H., Heesom, D., & Yenneti, K. (2024). Technological advancements and the vision of a meta smart twin city. Technology in Society, 79, 102731. https://doi.org/https://doi.org/10.1016/j.techsoc.2024.102731

Rodriguez Müller, A. P., Martin Bosch, J., & Tangi, L. (2024). An overview of the expected public values arising from blockchain adoption in the European public sector. International Journal of Public Sector Management, 38(1), 53–76. https://doi.org/https://doi.org/10.1108/IJPSM-12-2023-0363

Russo-Spena, T., Di Paola, N., & Mele, C. (2025). Configurational approaches to blockchain-enabled sustainability strategies. Business Process Management Journal, 31(8), 267–290. https://doi.org/https://doi.org/10.1108/BPMJ-06-2024-0450

Sánchez-García, E., Martínez-Falcó, J., Marco-Lajara, B., & Manresa-Marhuenda, E. (2024). Revolutionizing the circular economy through new technologies: A new era of sustainable progress. Environmental Technology & Innovation, 33, 103509. https://doi.org/https://doi.org/10.1016/j.eti.2023.103509

Shahzad, M. F., & Xu, S. (2024). Antecedents of international entrepreneurship and emerging technologies help to achieve sustainable development goals: Moderating role of global mindset. Technological Forecasting and Social Change, 209, 123831. https://doi.org/https://doi.org/10.1016/j.techfore.2024.123831

Sharma, G. D., Tiwari, A. K., Chopra, R., & Dev, D. (2024). Past, present, and future of block-chain in finance. Journal of Business Research, 177, 114640. https://doi.org/https://doi.org/10.1016/j.jbusres.2024.114640

Shinde, A., Mane, V., Ambulgekar, N., & Ansari, Z. (2024). Renewable Energy Trading Platform using Blockchain. Procedia Computer Science, 233, 243–253. https://doi.org/https://doi.org/10.1016/j.procs.2024.03.214

Sousa, C., Ferreira, R., Pinto, P., Pereira, C., & Rebelo, R. (2024). Digital Product Passport Architecture for Boosting Circularity in Footwear Industry. Procedia Computer Science, 239, 1560–1567. https://doi.org/https://doi.org/10.1016/j.procs.2024.06.331

Sze, L. B., Salo, J., & Tan, T. M. (2024). Sustainable innovation in the metaverse: Blockchain's role in new business models. Digital Business, 4(2), 100086. https://doi.org/https://doi.org/10.1016/j.digbus.2024.100086

Taiwo, O. A., Odeleye, J. A., Hassan, S. A., Onah, A. A., & Mohsin, R. Bin. (2025). Transporting the invisible hazard: Risk assessment and mitigation strategies for radioactive shipments. Next Research, 2(4), 100854. https://doi.org/https://doi.org/10.1016/j.nexres.2025.100854

Tesei, A., Lattuca, D., Luise, M., Pagano, P., Ferreira, J., & Bartolomeu, P. C. (2023). A transparent distributed ledger-based certificate revocation scheme for VANETs. Journal of Network and Computer Applications, 212, 103569. https://doi.org/https://doi.org/10.1016/j.jnca.2022.103569

van Haaren-van Duijn, B., Roca, J. B., de Groot, P., Romme, A. G. L., & Weggeman, M. (2024). Creating and Testing a Guideline for Governing Blockchain Ecosystems: A Study Informed by Design Science. She Ji: The Journal of Design, Economics, and Innovation, 10(3), 325–350. https://doi.org/https://doi.org/10.1016/j.sheji.2024.09.001

Verma, A., Prasad, V. K., Kumari, A., Bhattacharya, P., Srivastava, G., Fang, K., Wang, W., & Gadekallu, T. R. (2025). Industry 6.0: Vision, technical landscape, and opportunities. Alexandria Engineering Journal, 130, 139–174. https://doi.org/https://doi.org/10.1016/j.aej.2025.08.040

Wang, Y., Tripathi, S., Farshidi, S., & Zhao, Z. (2025). D-VRE: From a Jupyter-enabled private research environment to decentralized collaborative research ecosystem. Blockchain: Research and Applications, 6(1), 100244. https://doi.org/https://doi.org/10.1016/j.bcra.2024.100244

Xue, J., Li, G., & Ivanov, D. (2025). Digital transformation in the blockchain era: Balancing efficiency and resilience in operations management. International Journal of Production Economics, 282, 109525. https://doi.org/https://doi.org/10.1016/j.ijpe.2025.109525