BLOCKCHAIN IN BUSINESS: SCIENTIFIC BASIS, ECONOMIC IMPACT, AND CHALLENGES

Daxil olub: 6 oktyabr 2025-ci il
Qəbul olunub: 26 noyabr 2025-ci il

Received:6 October 2025
Accepted: 26 November 2025

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DOI:https://doi.org/10.30546/UNECSR.2025.04.2010

Abstract

This article provides a comprehensive analysis of blockchain technology as a transformative force in the digital economy, focusing on its scientific foundations, technical mechanisms, economic implications, and challenges for business adoption. Blockchain, as a distributed ledger technology, ensures decentralization, immutability, transparency, and data security, offering a fundamentally new way of organizing transactions and trust in economic systems. The study highlights its multidimensional impact across finance, supply chains, energy, healthcare, government services, and aviation, emphasizing how programmable transactions and smart contracts reshape business processes, reduce transaction costs, and enable new organizational forms. Special attention is given to asset tokenization, decentralized finance (DeFi), and central bank digital currencies (CBDCs), which represent innovative business models emerging from blockchain integration.

The article situates blockchain research within its historical and theoretical roots, starting with Satoshi Nakamoto's foundational 2008 paper, and traces the evolution of scientific literature from technical proofs of concept to systematic reviews addressing governance, regulation, and sustainability. Empirical studies from 2019–2024 show that blockchain generates the highest returns in contexts characterized by information asymmetry and complex intermediation, such as financial clearing or medical data sharing. At the same time, persistent barriers include scalability, interoperability, energy consumption, cyber threats, and fragmented regulation.

The rapid rise of Blockchain-as-a-Service (BaaS) further expands accessibility, allowing firms to integrate blockchain solutions without heavy infrastructure costs. However, achieving sustainable large-scale implementation requires resolving legal uncertainties, developing unified performance metrics, and addressing environmental concerns.

Overall, blockchain is analyzed not only as a technical tool but as a strategic instrument of digital transformation, reshaping business models, trust dynamics, and global economic interactions.

Keywords: *blockchain, digitalization, innovation, decentralization, challenges*.

БЛОКЧЕЙН В БИЗНЕСЕ: НАУЧНАЯ ОСНОВА, ЭКОНОМИЧЕСКОЕ ВЛИЯНИЕ И ПРОБЛЕМЫ

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Резюме

В данной статье предоставлен всесторонний анализ технологии блокчейн как преобразующей силы в цифровой экономике с акцентом на её научные основы, технические механизмы, экономические последствия и проблемы внедрения в бизнес. Блокчейн, как технология распределённого регистра, обеспечивает децентрализацию, неизменность, прозрачность и безопасность данных, предлагая принципиально новый способ организации транзакций и доверия в экономических системах. В исследовании подчёркивается его многомерное влияние на финансы, логистику поставок, энергетику, здравоохранение, государственные услуги и авиацию, а также то, как программируемые транзакции и смарт-контракты преобразуют бизнес-процессы, снижают транзакционные издержки и открывают новые организационные формы. Осо-бое внимание уделяется токенизации активов, децентрализованным финансам (DeFi) и цифровым валютам центральных банков (CBDC), которые представляют собой инновационные бизнес-модели, возникающие в результате интеграции блокчейна.

В статье рассматриваются исторические и теоретические корни исследований блокчейна, начиная с основополагающей работы Сатоши Накамото 2008 года, и прослеживается эволюция научной литературы от технических обоснований концепции до систематических обзоров, посвященных вопросам управления, регулирования и устойчивого развития. Эмпирические исследования 2019–2024 годов показывают, что блокчейн генерирует наибольшую прибыль в условиях информационной асимметрии и сложного посредничества, таких как финансовый клиринг или обмен медицинскими данными. В то же время сохраняются такие препятствия, как масштабируемость, совместимость, энергопотребление, киберугрозы и фрагментированное регулирование.

Стремительный рост «блокчейн как услуги» (BaaS) дополнительно расширяет доступность, позволяя компаниям интегрировать блокчейн-решения без значительных затрат на инфраструктуру. Однако для достижения устойчивого крупномасштабного внедрения необходимо разрешить правовые неопределенности, разработать единые показатели эффективности и решить экологические проблемы.

В целом блокчейн рассматривается не только как технический, но и как стратегический инструмент цифровой трансформации, изменения бизнес-моделей, динамики доверия и глобального экономического взаимодействия.

Ключевые слова: *блокчейн, цифровизация, инновации, децентрализация, вызовы.*

BİZNESDƏ BLOKCHAİN: ELMİ ƏSASLAR, İQTİSADİ TƏSİR VƏ PROBLEMLƏR

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Xülasə

Bu məqalə rəqəmsal iqtisadiyyatda transformasiyaedici qüvvə kimi blokçeyn texnologiyasının hərtərəfli təhlilini təqdim edir, onun elmi əsaslarına, texniki mexanizmlərinə, iqtisadi nəticələrinə və biznesin həyata keçirilməsində çətinliklərə diqqət yetirir. Blokçeyn, paylanmış kitab texnologiyası olaraq, qeyri-mərkəzləşməni, dəyişməzliyi, şəffaflığı və məlumat təhlükəsizliyini təmin edərək, əməliyyatları təşkil etmək və iqtisadi sistemlərə etibar etmək üçün tamamilə yeni bir üsul təklif edir. Tədqiqat onun maliyyə, təchizat zəncirinin logistikası, enerji, səhiyyə, dövlət xidmətləri və aviasiyaya çoxölçülü təsirini və proqramlaşdırıla bilən əməliyyatların və ağıllı müqavilələrin biznes proseslərini necə dəyişdirdiyini, tranzaksiya xərclərini azaltdığını və yeni təşkilati formaları təmin etdiyini vurğulayır. Blokçeynin inteqrasiyasından yaranan innovativ biznes modelləri olan aktivlərin tokenləşdirilməsinə, mərkəzləşdirilməmiş maliyyəyə (DeFi) və mərkəzi bankın rəqəmsal valyutalarına (CBDC) xüsusi diqqət yetirilir.

Bu məqalə Satoshi Nakamoto-nun 2008-ci ildəki əsas məqaləsindən başlayaraq blokçeyn tədqiqatının tarixi və nəzəri köklərini araşdırır və elmi ədəbiyyatın konsepsiyanın texniki əsaslandırılmasından idarəetmə, tənzimləmə və davamlılığa yönəlmiş sistematik təhlillərə qədər təkamülünü izləyir. 2019-2024-cü illərdə aparılan empirik tədqiqatlar göstərir ki, blokçeyn informasiya asimmetriyası və maliyyə klirinq və ya tibbi məlumat mübadiləsi kimi mürəkkəb vasitəçilik şəraitində ən

yüksək gəlir gətirir. Eyni zamanda, miqyaslılıq, qarşılıqlı fəaliyyət, enerji istehlakı, kiber təhlükələr və parçalanmış tənzimləmə kimi maneələr qalmaqdadır.
Blokçeynin bir xidmət kimi sürətli inkişafı (BaaS) əlçatanlığı daha da genişləndirir, şirkətlərə əhəmiyyətli infrastruktur xərcləri olmadan blokçeyn həllərini inteqrasiya etməyə imkan verir. Bununla belə, davamlı genişmiqyaslı icraya nail olmaq üçün hüquqi qeyri-müəyyənliklər aradan qaldırılmalı, ümumi fəaliyyət göstəriciləri işlə-nib hazırlanmalı və ekoloji problemlər həll edilməlidir.
Bütövlükdə, blokçeyn təkcə texniki deyil, həm də rəqəmsal transformasiya, dəyişən biznes modelləri, inam dinamikası və qlobal iqtisadi qarşılıqlı əlaqə üçün strateji vasitə kimi nəzərdən keçirilir.

Açar sözlər: *blokçeyn, rəqəmsallaşma, innovasiya, mərkəzsizləşdirmə, problemlər.*

INTRODUCTION

Blockchain has become a fundamental digital technology that provides decentralized accounting, programmable transactions, and secure data origin. Its impact extends to finance, supply chains, energy markets, and organizational management. Scholars from various disciplines economics, information systems, and law have explored its transformative potential (Swan, 2015; Tapscott & Tapscott, 2016; De Filippi & Wright, 2018) [1; 2; 3].

The purpose of this article is to provide a comprehensive analysis of blockchain as a technological phenomenon, assessing its real and potential economic impact on business in the context of global digitalization in 2019–2032. In particular, the work aims to identify the scientific basis for the functioning of blockchain, determine the mechanisms of its impact on the economy of enterprises and industries, and outline the opportunities and challenges accompanying the integration of this technology into the modern business environment.

The relevance of the study is determined by several factors, namely: global digitalization of the economy (1); rapid market growth (2); interdisciplinary influence (3); the presence of serious challenges (4); the need for a strategic vision for business (5). In the context of the transition to Industry 4.0 and Web3, blockchain is becoming a key technology that ensures transparency, security, and automation of business processes (1). According to forecasts, in 2022–2032, the global market for blockchain solutions will grow by ~38–40% annually, reaching hundreds of billions of dollars, which indicates the enormous economic potential of the technology (2). Blockchain is simultaneously transforming finance, logistics, healthcare, govern-ment services, aviation, and other sectors, opening up new business models (asset

tokenization, DeFi, central bank digital currencies) (3). Despite the prospects, the implementation of blockchain is accompanied by problems of scalability, energy costs, cyber threats, and regulatory uncertainty, which requires thorough scientific analysis (4). It is important for businesses to understand not only the technical essence of blockchain, but also its economic feasibility in order to minimize risks and maximize benefits in the context of competition and digital transformation (5).

Analysis of recent studies and publications

The historical starting point for blockchain research is Satoshi Nakamoto's classic paper «Bitcoin: A Peer-to-Peer Electronic Cash System» (2008), which laid the fundamental principles of distributed ledgers, consensus mechanisms, and trustless systems. This text continues to serve as the theoretical basis for most subsequent research in the field. (bitcoin.org) [4].

In 2018, K.E. Babenko reviewed the role of blockchain in the economy and business, emphasizing the opportunities for increasing transparency and reducing transaction costs (Babenko, 2018). This local contribution is important for understanding regional approaches to implementation and regulatory barriers. (Babenko K.E., 2018) [5].

From 2019 to 2024, the literature has transformed from applied PoC studies to systematic reviews comparing architectures, consensuses, and business models. Review articles and systematic reviews in recent years highlight three main areas: (1) technical improvements (sharding, L2 solutions, zk-drives for privacy), (2) economic cases (tokenization, DeFi, supply chain optimization), and (3) institutional and regulatory issues (interpretation of tokens, consumer protection). Contemporary systematic reviews provide a comprehensive overview of empirical results and gaps in the literature (ScienceDirect) [6].

Technical changes in recent years have significantly influenced scientific discourse. The most notable event was the transition of the Ethereum network from Proof-of-Work to Proof-of-Stake (The Merge, September 15, 2022), which radically reduced the network's energy consumption (~99.9%) and shifted researchers' attention to environmental sustainability, hybrid validator models, and the legal implications of the transition. This update has helped to renew interest in academic and corporate research on scaling and sustainability [7].

Applied publications from 2020–2024 demonstrate the accumulation of empirical cases in finance, logistics, healthcare, and energy. Such studies show that in scenarios with strong information asymmetries and a large number of intermediaries,

blockchain provides the highest economic return (reducing audit costs, speeding up clearing, reducing fraud). At the same time, reviews point to recurring methodological problems: the lack of unified performance metrics, short horizons for field experiments, and poor replication of results [8].

A separate layer of literature is devoted to corporate and government experiments: CBDC research, industry consortia (supply-chain blockchain), as well as regulatory documents from the EU and international organizations, which are gradually forming recommendations for the unification of standards and financial regulation. These works show that security, interoperability, and law remain key barriers to large-scale implementation [9].

The conceptual origins of blockchain can be traced back to Nakamoto's white paper (2008), in which Bitcoin was presented as a peer-to-peer electronic cash system [10]. Subsequent scholars expanded the scope of research: Crosby et al. (2016) highlighted the application of blockchain beyond cryptocurrencies [11]; Ili-Huomo et al. (2016) provided a systematic overview of research directions and limitations [12]; and Szabo (1996) laid the foundations for smart contracts [13], which were later developed in the context of enterprises (Christidis & Devetsikiotis, 2016) [14]. From an economic perspective, Catalini and Gans (2016) analyzed the impact of blockchain on transaction costs and intermediaries [15].

The article by Mettler M. (2016) “Blockchain technology in healthcare: The revolution starts here,” presented at the 18th IEEE International Conference on e-Health Networking, Applications and Services (Healthcom), examines the potential of blockchain technology in healthcare. The author emphasizes that blockchain can provide a single, immutable registry of patient medical records, allowing for seamless data exchange between healthcare institutions while maintaining confidentiality through encryption and access control. In addition, the transparency and immutability of blockchain can improve the traceability of pharmaceutical products and medical devices, helping to combat counterfeit drugs and ensure regulatory compliance [16].

In the article Attaran M. (2020) “Blockchain technology in healthcare: Challenges and opportunities,” published in the International Journal of Healthcare Management, the author analyzes the challenges and opportunities of implementing blockchain technology in healthcare. The study highlights existing blockchain-based products in healthcare and discusses the advantages and limitations of this technology in medical practice [17].

The article by Haleem A., Javaid M., Singh R.P., Suman R., Rab S. (2021) – "Blockchain Technology Applications in Healthcare: An Overview," published in the International Journal of Intelligent Networks, provides a comprehensive overview of the application of blockchain technology in healthcare. The authors discuss the benefits, challenges, and prospects of integrating blockchain into healthcare systems, particularly in storing and sharing patient data, managing medical supply chains, and ensuring transparency in clinical trials [18].

However, we believe it is necessary to define the scientific basis for the functioning of blockchain, the mechanisms of its impact on the economy of enterprises and industries, and to outline the opportunities and challenges that accompany the integration of this technology into the modern business environment.

Main part and presentation of the material

Blockchain changes economic interactions, primarily by reducing verification and enforcement costs, thereby displacing traditional intermediaries such as banks or clearing houses (Catalini & Gans, 2016) [15]. The tokenization of assets opens up opportunities for liquidity and fractional ownership (Tapscott & Tapscott, 2016) [19]. However, network effects create implementation problems, as a critical mass is required for systems to function effectively (Swan, 2015) [1].

Proof-of-work consensus models provide security but also create negative externalities in the form of energy costs (Yli-Huumo et al., 2016) [12]. Alternative models, such as proof-of-stake, promise efficiency but raise questions about governance and centralization. At the macroeconomic level, blockchain adoption interacts with financial stability, regulatory compliance, and international capital flows (De Filippi & Wright, 2018) [3].

For managers, blockchain transforms the dynamics of trust by embedding verification in code rather than institutions (Crosby et al., 2016) [11]. Smart contracts automate workflows, ensuring the efficiency of supply chains and financial services (Christidis & Devetsikiotis, 2016) [14]. Transparency through immutable records improves auditing and compliance processes. However, decentralized networks face governance issues where consensus on updates or disputes remains contentious (De Filippi & Wright, 2018) [3].

Fortune Business Insights: According to their report, the global blockchain technology market was valued at USD 20.16 billion in 2024 and is projected to grow to USD 393.42 billion by 2032 at a compound annual growth rate (CAGR) of ≈ 43.65% [20]. In 2024, global expenditures on blockchain technologies already

exceeded USD 20.16 billion, with more than 40% of the total market share attributed to North America (Fortune Business Insights, 2025) [21].

One of the key drivers of this rapid expansion is the ongoing digital transformation, particularly within the financial sector. Blockchain ensures a high level of security and trust that is essential for contemporary digital transactions by creating a decentralized, tamper-resistant system for recording operations. Once entered into the ledger, transactions cannot be altered. Traditional financial institutions, such as banks and stock exchanges, are increasingly adopting blockchain services to manage online payments, accounts, and other digital operations. Furthermore, blockchain's programmability enables the use of smart contracts self-executing agreements that automatically initiate actions, payments, or events once predefined conditions are met.

Beyond finance, retail companies are implementing blockchain solutions to monitor the flow of goods between suppliers and customers, enhancing transparency and efficiency in supply chains. In the energy sector, blockchain supports sustainable development goals by enabling peer-to-peer trading platforms for energy resources and facilitating access to renewable energy sources.

The study also highlights the accelerating growth of Blockchain-as-a-Service (BaaS). In this model, blockchain is provided as a managed cloud-based service, where enterprises focus on developing applications and digital solutions, while service providers deliver the necessary infrastructure and tools. This approach enhances efficiency, flexibility, and cost-effectiveness, making blockchain adoption more accessible to a wider range of industries.

Despite its significant prospects, blockchain faces limitations. Technical issues such as scalability and interoperability remain unresolved (Yli-Huumo et al., 2016) [12]. The environmental costs of energy-intensive consensus mechanisms undermine sustainability goals (Catalini & Gans, 2016) [15]. The legal enforceability of smart contracts and fragmented regulation create uncertainty for businesses (De Filippi & Wright, 2018) [3]. In addition, the concentration of mining power and the dominance of individual service providers contradict the decentralized philosophy of blockchain (Tapscott D. & Tapscott A., 2016) [2].

Let us conduct a theoretical analysis of blockchain in terms of its main aspects: conceptual framework (1); technical and managerial implications (2); economic mechanisms and implications (3):

1). Blockchain is a distributed ledger technology (DLT) that allows a network of participants to reach consensus on the state of a shared ledger without a central

authority. Its two main properties are immutability (records can only be added) and decentralization (multiple validators). Options include public permissionless chains (e.g., Bitcoin, Ethereum) and permissioned/private chains (Hyperledger, Corda) for enterprise use.

2). Technical and managerial implications (reconfiguration of trust, automation through smart contracts, data provenance and transparency, new organizational forms).

• Trust reconfiguration – blockchain replaces some forms of institutional trust (banks, registries) with cryptographic proofs and consensus protocols. For managers, this means revising management and control systems: who manages the nodes, how consensus decisions are made, and what incentives bind participants.

• Automation through smart contracts – business logic encoded in the chain allows payments, transfers of rights, or work processes to be executed under certain conditions, reducing the need for manual verification and speeding up settlements.

• Data origin and transparency – supply chain origin, immutable audit trails, and tamper-proof records improve accountability and enable certification or compliance processes.

• New organizational forms – tokenization and decentralized autonomous organizations (DAOs) enable experimentation with new incentive structures and cross-border coordination without traditional hierarchies.

3). Economic mechanisms and consequences (Fig. 1).

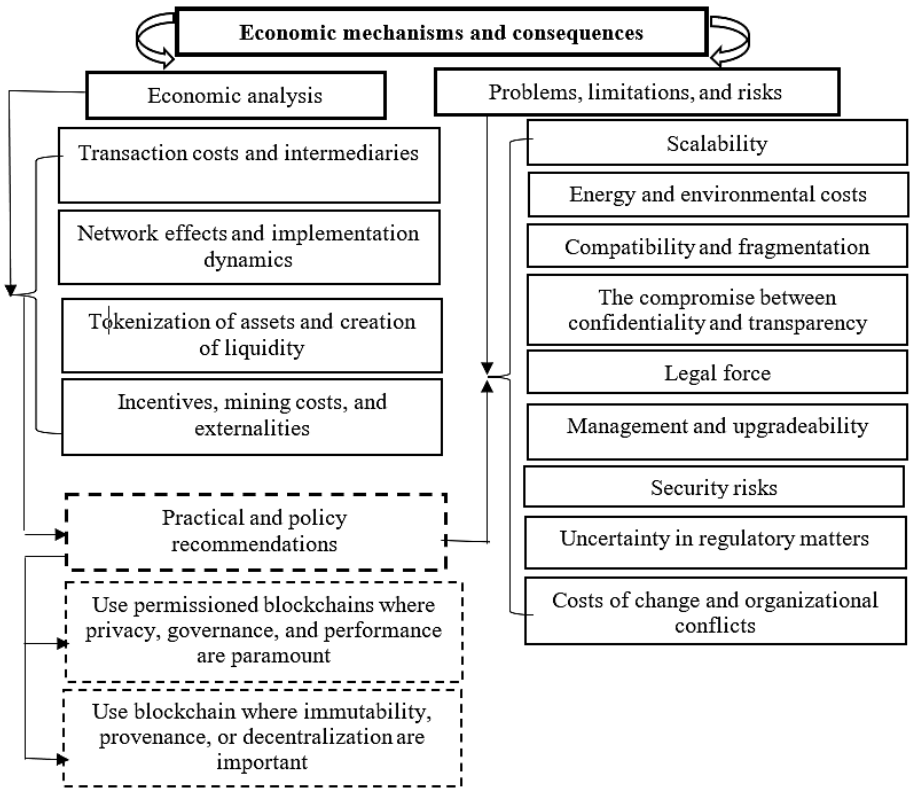

Fig. 1. Economic mechanisms of blockchain

If we look more closely at the transaction costs associated with blockchain and their impact on intermediaries, as noted by Catalini & Gans (2016), blockchain can reduce certain transaction costs, particularly verification and enforcement costs, by providing publicly verifiable records and coded enforcement (smart contracts). Lower verification costs can undermine the value of intermediaries (escrow, registries, clearing houses). However, some costs are replaced rather than eliminated (e.g., consensus costs, infrastructure costs).

Regarding network effects and adoption dynamics, blockchain systems exhibit strong network effects: value for users increases with the number of participants (greater liquidity, richer data). However, there are chicken-and-egg adoption problems: participants may wait for others or for standards/interoperability. Permissioned blockchains can shorten this process by inviting known participants.
Tokenization converts rights to assets (real estate, invoices, carbon emission quotas) into tradable digital tokens, potentially improving liquidity and fractional ownership. This can unlock capital, but raises questions of regulation and custody.

Proof-of-Work systems internalize security through mining rewards but impose external costs (energy consumption). Alternative consensus mechanisms (Proof-of-Stake, BFT variants) trade energy for varying levels of trust and centralization.

Let's briefly review the essence of the problems, limitations, and risks presented in Figure 1:

1. Scalability – bandwidth limitations and delays constrain large-volume, real-time applications (although layer 2 approaches and sharding attempt to mitigate this).
2. Energy and environmental costs – PoW consensus is energy-intensive; environmental impact is a reputational and regulatory risk.
3. Compatibility and fragmentation – many competing protocols hinder seamless asset transfers and network effects.
4. Trade-off between privacy and transparency – public ledgers are transparent by design; confidential business processes require off-chain solutions or privacy-preserving designs (zk-SNARKs, permissioned ledgers).
5. Legal force – smart contracts may not correspond to legal contracts; uncertainty regarding jurisdiction remains.
6. Governance and upgradeability – decentralized systems face challenges with development (hard forks, governance takeovers).
7. Security risks – coding errors, oracle manipulation, and key management failures lead to real economic losses.
8. Regulatory uncertainty – inconsistent treatment of tokens, securities, and data across jurisdictions hinders adoption in the corporate sector.
9. Change costs and organizational conflicts – replacing outdated processes and stakeholder beliefs involves significant transition costs.

Practical recommendations (Table 1).

Table 1 Practical recommendations

№	**Choosing the type of blockchain depending on the context**	
1.1	Permissioned blockchains are appropriate for sectors where confidentiality, control, and performance are key.	Interbank clearing and settlements: transaction speed, controlled access, regulatory compliance
		Consortia in logistics and supply chains: sharing data among participants, but with the ability to control access and prevent leaks of commercial information
1.2	Public (permissionless) blockchains should be used where the main principle is decentralization, immutability, and verifiability of origin.	Electoral systems, electronic voting, public registers
		Labeling of goods for traceability (food industry, pharmaceuticals, art objects)
		Platforms for NFTs and Intellectual Property

1.3	Ensuring scalability and performance	Using hybrid solutions (combination of public and private blockchain).
		Optimization of consensus algorithms (Proof-of-Authority, Proof-of-Stake instead of Proof-of-Work)
1.4	Focus on cybersecurity and personal data protection	Anonymization and encryption of transactions
		Compliance with GDPR standards in the EU
		Using smart contracts with independent security audit
	Policy recommendations	
2.1	Regulatory Framework	Clearly define the legal status of digital assets, tokens and smart contracts
		Implement rules for the activities of blockchain consortia and ensure transparency in their work
		Harmonize legislation with international standards (EU, FATF, ISO)
2.2	Regulatory Control and Balance of Innovation	Avoid excessive regulation that hinders the development of innovation
		Create sandboxes for blockchain startups where they can test new models without harsh sanctions
		Develop policies to combat money laundering and terrorist financing using blockchain solutions
2.3	Institutional Support and Education	Government investments in blockchain infrastructure for healthcare, land cadastres, public services
		Training programs for officials and businesses on the practical application of blockchain
		Partnerships with universities to develop research and train specialists
2.4	International Cooperation	Participation in global blockchain development alliances
		Using common platforms for cross-border payments, customs control, environmental monitoring.

Highlights

- Proposes an interdisciplinary framework linking economic, technical, and managerial aspects of blockchain;
- Demonstrates how blockchain reduces verification/enforcement costs and enables tokenization;
- Provides practical recommendations for selective implementation in finance, supply chains, and energy;
- Shows measurable economic effects through cost savings, liquidity, and automation;
- Identifies key limitations: scalability, energy costs, fragmented regulation, and governance risks;
- Suggests future research on empirical evaluation, regulatory design, and governance models.

CONCLUSION

Blockchain is a transformative technology that has the potential to reshape trust, transaction costs, and organizational forms in various sectors. From an economic point of view, it reduces some of the contradictions regarding verification and enforcement and allows for the creation of new business models (tokenization, decentralized markets). However, these prospects are limited by technical constraints, external environmental factors, governance issues, and regulatory uncertainty.

For managers and policymakers, a pragmatic approach is selective implementation: matching blockchain capabilities to clearly defined economic problems, favoring permissioned or hybrid architectures where appropriate, and investing in governance and legal clarity. Assessing the long-term impact on markets and institutions requires interdisciplinary research that combines technical, economic, and legal perspectives. Blockchain has enormous potential, but its effectiveness depends on the right choice of type (public/private), balanced regulatory policy, government support, and international coordination.

Blockchain shows significant potential to transform business models by reducing transaction costs, increasing transparency, and enabling automation. However, its transformative power is limited by unresolved issues of scalability, governance, and regulation. Thus, selective implementation appears most appropriate, especially in contexts that require a high level of trust and provenance. Future research requires interdisciplinary approaches combining economics, law, and technology to fully assess the long-term social and economic impact of blockchain.

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