An Empirical Review of State-of-the-Art Agro Food Supply Chain Using Blockchain Technology

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Abstract – *The agro-food supply chain is a complex network involving multiple stakeholders, from farmers to consumers, and is often burdened by issues such as lack of transparency, traceability, inefficiencies, and food safety concerns. Recent advancements in blockchain technology and deep learning have the potential to address these challenges by improving data integrity, automating decision-making, and optimizing supply chain processes. This literature review provides an in-depth examination of the integration of blockchain technology and deep learning in the agro-food supply chain. Blockchain technology, with its decentralized, transparent, and immutable ledger system, offers a promising solution for ensuring traceability and accountability in the agro-food supply chain. By enabling real-time tracking of products from farm to table, blockchain can help mitigate issues such as fraud, contamination, and inefficiency. Deep learning, a subset of artificial intelligence (AI), complements blockchain by providing advanced data analytics capabilities. Through models such as recurrent neural networks (RNNs), deep learning can predict demand, optimize logistics, and ensure food quality through automated inspection systems. It has been applied in areas such as crop yield prediction, disease detection, and supply chain optimization. This review discusses how deep learning's ability to analyze vast datasets can drive efficiency in agro-food supply chains, improving decision-making, reducing waste, and enhancing food quality. In conclusion, while blockchain and deep learning offer significant potential for revolutionizing the agro-food supply chain, their successful integration requires overcoming several technical, economic, and regulatory challenges. This literature review underscores the importance of continued research and collaboration between industry and academia to unlock the full potential of these technologies and build more efficient, transparent, and sustainable agro-food supply chains.*

Keywords: Blockchain, Deep learning, Food supply chain, recurrent neural network

I- INTRODUCTION

The agro-food supply chain, which connects agricultural producers with consumers, plays a critical role in ensuring global food security and safety. However, this supply chain is often plagued by challenges such as inefficiencies, lack of transparency, poor traceability, fraud, and food contamination. Traditional supply chain management practices struggle to address these challenges due to their centralized and fragmented nature, leading to issues like food waste, mislabelling, and delays in responding to food safety incidents.

In recent years, emerging technologies such as blockchain and deep learning have shown promise in transforming the agro-food supply chain by addressing its key inefficiencies and improving transparency, traceability, and decision-making. Blockchain technology, with its decentralized, transparent, and immutable ledger, has the potential to revolutionize the way food products are tracked and verified across the supply chain. It ensures secure and tamper-proof data sharing among all stakeholders, from farmers to retailers, improving accountability and reducing fraud. Blockchain can also enable real-time traceability, allowing for quick responses to food safety issues, such as recalls due to contamination.

On the other hand, deep learning, a subset of artificial intelligence, provides advanced data analytics capabilities that can enhance decision-making within the agro-food supply chain. Deep learning algorithms like recurrent neural networks (RNNs), can process large datasets to predict demand, optimize logistics, monitor crop health, and assess food quality. By automating these processes, deep learning can help reduce operational inefficiencies, lower food waste, and improve overall supply chain resilience.

The integration of blockchain technology and deep learning offers a powerful combination for addressing many of the persistent challenges within the agro-food supply chain. Blockchain ensures the integrity and security of supply chain data, while deep learning enhances predictive analytics and process automation. Together, they can create a more transparent, efficient, and secure supply chain, benefiting both producers and consumers.

Motivation

The motivation behind this work stems from the challenges faced in the traditional agro-food supply chain, including inefficiencies, lack of transparency, and food safety concerns. The agro-food supply chain is often marred by issues such as unpredictable crop yields, suboptimal supply chain routes, and fraudulent activities. These challenges lead to significant economic losses, food wastage, and compromised food safety. There is a need for innovative solutions that leverage advanced technologies to address these issues.

Predictive analytics using DL can help farmers and stakeholders make informed decisions by providing accurate crop yield predictions and early warnings for pest and disease outbreaks. Supply chain optimization using DL can enhance the efficiency of transportation, reduce costs, and ensure timely delivery of goods. Blockchain technology can improve traceability, ensure data integrity, and prevent fraudulent activities. By integrating these technologies, we aim to create a more efficient, transparent, and safe agro-food supply chain.

The motivation to integrate blockchain technology and deep learning in the agri-food supply chain is driven by the need to improve traceability, transparency, efficiency, quality assurance, and sustainability. Blockchain ensures the integrity and reliability of supply chain data, while deep learning facilitates advanced analytics and automation that lead to better decision-making, reduced costs, and increased trust among stakeholders. Together, these technologies offer a comprehensive solution for modernizing the agro-food supply chain and addressing its inherent challenges.

II - LITERATURE SURVEY

The paper proposes a blockchain-based supply chain information-sharing mechanism. It addresses supply chain information security management issues. The system enhances information reliability and adaptability. It aims to improve supply chain dynamic capabilities. The study highlights factors influencing information sharing in supply chains[1]. The paper presents Agri-4-All framework for agriculture supply chains. It integrates IoT, blockchain, and smart contracts. The framework automates intra- and inter-organizational processes. Cost analysis of smart contracts is included. The methodology utilizes Business Process Modeling (BPM).It addresses security, privacy, and auditing in supply chains. The framework is compliant with Industry 4.0 standards[2].The paper presents a secure supply chain management framework. It utilizes IoT and blockchain technologies for transparency. The framework addresses traditional supply chain management issues. An optimal queue model enhances service request management. Experimental results demonstrate the framework's effectiveness and feasibility[3].The paper proposes a blockchain-based fishery supply chain solution.It enhances traceability, security, and transparency in fish products. Five smart contracts automate operations and track events. The solution is tested and validated for effectiveness. Future plans include deployment on the real Ethereum network[4]. The paper proposes blockchain-based inventory sharing for supply chains. It enhances trust, efficiency, and transparency among stakeholders. Smart contracts facilitate secure communication between suppliers and retailers. The solution is adaptable across various supply chain industries. Cost and security analyses validate the proposed approach [5].The paper explores blockchain's impact on supply chain management. It focuses on Proof of Delivery (PoD) process management. Smart contracts enhance delivery efficiency and reliability. Complexity limits performance measurement capabilities of smart contracts. Transaction costs can be reduced with blockchain-based performance measurement. Transparency and trust are key to reducing transaction costs [6]. The paper examines blockchain technology's role in supply chain management. It highlights challenges in traditional supply chain practices. Blockchain enhances transparency, safety, and efficiency in transactions. The study analyzes various blockchain applications in SCM. Future research directions for blockchain in SCM are discussed [7]. The paper studies blockchain's impact on green supply chain finance.It analyzes financing methods: bank, prepayment, and in-house factoring. Manufacturer's profit relates linearly to carbon reduction efficiency. Retailer's profit shows a U-shaped relationship with online market share. Blockchain technology enhances profitability and emission reduction in supply chains [8]. The paper discusses blockchain smart contracts in supply chain management. It simulates a serious game for agricultural transactions. The system enhances transparency and efficiency without intermediaries. It integrates decentralized data sharing for better traceability. Smart bidding optimizes prices and increases farmers' profits [9]. The paper presents a Proof of Concept for IoT and blockchain integration. It addresses supply chain transparency, data visibility, and security challenges. IoT devices autonomously sign transactions using authenticated private keys. The approach enhances scalability, efficiency, and real-time responsiveness. A detailed workflow and simulation results are provided. The PoC code is publicly available on GitHub [10].

Reference	Method Used	Findings	Limitations
[1]Blockchain-Based Supply Chain Information Sharing Mechanism.	Blockchain application for supply chain information sharing. Multisource data analysis center for dataprocessing. Information block recording method for internal and external data.	The model includes internal and external data source integration. The method improves information reliability and system network effects.	The provided contexts do not mention any limitations of the research paper.
[2] Agri-4-All: A Framework for Blockchain Based Agricultural Food Supply Chains in the Era of Fourth Industrial Revolution	Business Process Modeling (BPM) is utilized for supply chain analysis. Smart contracts are tested on the Ganache network. Hybrid algorithms minimize gas fees in smart contracts. Information is mapped onto the RAMI 4.0 framework.	Intra-organizational smart contracts reduce gas costs significantly. Framework enhances transparency and security in supply chains. Limitations include interoperability and privacy issues not adequately addressed.	The framework does not address interoperability of blockchains. Stakeholder's privacy issues are inadequately managed.
[3] An IoT and Blockchain-Based Secure and Transparent Supply Chain Management Framework in Smart Cities Using Optimal Queue Model	Blockchain technology for secure data management. IoT integration for real-time visibility. RF-PO-Queue optimization for service quality.Smart contracts to automate processes. Edge computing servers for data processing.	The RF-PO algorithm reduces end-to-end delay and queue length. It ensures product traceability and compliance in regulated industries. The model automates processes, reducing manual errors and delays.	Traditional systems face single-point failure issues. Lack of data integrity and transparency in existing models. High energy dependency of blockchain technology.
[4]Blockchain-Based Traceability for the Fishery Supply Chain	Ten algorithms are implemented for system functionality. Security analysis ensures solution's trustworthiness and safety. Decentralized Applications (DApps).	Five smart contracts were developed to automate supply chain operations. Ten algorithms were implemented for effective process management.	The provided contexts do not mention any specific limitations of the paper.
[5]Supply Chain Inventory Sharing Using Ethereum Blockchain and Smart Contracts	Decentralized storage technology is implemented on the Ethereum network. A series of functions and events are captured in	It improves information connectivity among supply chain stakeholders. The approach utilizes smart contracts on a private	Trust issues hinder information sharing among stakeholders. Sensitive information sharing poses privacy concerns. High

	sequence diagrams. Reputation scores for suppliers are maintained through smart contracts. Security vulnerabilities are analyzed in the proposed solution. Cost analysis for stakeholder transactions is provided.	Ethereum network. Detailed algorithms capture stakeholder interactions and enhance trust. The system architecture is adaptable to various product categories.	investment costs impede information sharing adoption. Lack of reliable data affects cooperation success. Divergent KPIs complicate data sharing and trust.
[6]Proof of Delivery Smart Contract for Performance Measurements	An experimental design science approach is applied. Development of an open-source blockchain for supply chain management. Pre-contractual negotiation processes are established for agreements. Algorithms control delivery order processing and performance evaluation.	Pre-contractual steps are essential for effective blockchain design. DLTs improve transparency and trust in supply chain processes. Performance measurement requires negotiation of business protocols among partners. DLT architecture supports automated payoffs and dispute resolutions.	Limited capability to measure performance accurately. Requires further development for qualitative inspections. Asymmetric performance information increases evaluation costs. Pre-contractual negotiation processes are necessary but not always implemented
[7] An Examination of Distributed and Decentralized Systems for Trustworthy Control of Supply Chains.	Comprehensive assessment of blockchain implementation progress in SCM. Evaluation of blockchain architecture and consensus algorithms. Exploration of counterfeit product impacts on distribution networks	Counterfeit products negatively impact customer satisfaction in supply chains Decentralized systems can prevent fraudulent activities in supply chains.	Coordination and control of stocks are challenging. Reliance on staff members complicates order supervision. Susceptibility to product counterfeiting and fraud. Delays in the supply chain impact stakeholders.
[8]Research on Low-Carbon Dual-Channel Supply Chain Emission Reduction and Financing Strategy Based on Blockchain.	Bank financing method is utilized. Zero-interest early payment financing method is applied. In-house factoring financing method is employed. Stackelberg game model is used for analysis.	Manufacturer's profit relates linearly to carbon reduction efficiency. Retailer's profit and online market share show a U-shaped relationship. Critical points exist for production cost and carbon reduction efficiency.	The provided contexts do not mention any specific limitations of the paper.
[9]Supply Chain Management Serious Game Using Blockchain Smart Contract	Serious games simulate supply chain management scenarios. Smart bidding optimizes prices in agricultural transactions. User registration via smart contracts and MetaMask wallet.	Blockchain technology enhances transparency in supply chain transactions. New distribution channels optimize agricultural product sales. Automated bidding increases profits for farmers.	The research focuses on the Indonesian case study. Blockchain implementation faces challenges with capacity and speed. Requires minimum specifications for effective blockchain performance.

[10]Enhancing Supply Chain Efficiency and Security: A Proof of Concept for IoT Device Integration With Blockchain	Integration of IoT devices with blockchain technology.Development of an IoT layer for data collection. Use of smart contracts for blockchain updates.	IoT devices autonomously sign transactions using authenticated private keys. The PoC code is publicly available on GitHub. The study addresses challenges in transaction processing and data sharing.	Traditional supply chains face transparency and data visibility issues. Centralized systems are vulnerable to tampering and security risks. Stakeholders lack relationships and data visibility in supply chains
[11]Blockchain Based Deep Learning for sustenbility.	Deep Random Forest (DRF) for quality evaluation. Decision Tree (DT) for predictive learning.	Blockchain technology enhances food traceabilityaccuracy. Deep Random Forest improves computing efficacy and response time.	The provided contexts do not mention any limitations of the study.
[12] Implementation of Circular Blockchain-Based Approach for Food Crops Supply Chain with Bitcoin Prediction using Deep Learning	Long Short-Term Memory (LSTM) for bitcoin price prediction. Support Vector Machine (SVM) for classification and regression.Naive Bayes for forecasting food commodity prices.Simple Exponential Smoothing for price trend analysis.	LSTM predicts bitcoin prices with 88.67% accuracy. Traditional algorithms like SVM and Naive Bayes show lower accuracy. Circular blockchain provides immutability and tamper resistance for data. Stakeholders can optimize buying and selling times for crops.	High processing cost of SVM method. Large memory utilization of SVM method. Decreased accuracy of Naive Bayes with smaller datasets**.**
[13] ABlockchain-Driven Food SupplyChain Management Using QR Codeand XAI-Faster RCNN Architecture	Explainable AI-based Faster RCNN model for food evaluation. Elliptic Curve Integrated Encrypted Scheme for data validation. Shapley Additive Explanation for laboratory test legal plea.	The proposed method achieved 99.53% accuracy with minimal processing time. It utilizes XAI-based Faster RCNN for food product evaluation. ECIES-based blockchain enhances security in food supply chain.	Product properties are not analyzed in existing literature. Users cannot verify the food source in some systems.
[14]Blockchain Database and IoT: A Technology Driven Agri-Food Supply Chain.	In-depth review of selected studies for relevant insights. Case study analysis of a blockchain-based platform with IoT sensors.	Increased transparency reduces waste in the supply chain. Technologies transform the agro-food industry towards sustainability. IoT helps farmers monitor crop quality effectively. Processors ensure food safety standards with IoT monitoring.	Challenges related to interoperability among technologies. Issues with scalability of blockchain and IoT solutions. Security concerns affecting widespread technology adoption

[15]Agri food supply chain using blockchain	Quality inspectors assess harvests and record findings in a ledger. Processors sell goods to retailers, maintaining a transparent record. Immutable chains provide point-to-point updates for efficiency.	Customers can access information about food processing and safety. The system reduces transaction costs and speeds up processes. It utilizes IoT and HACCP for reliable data transmission.	Challenges in administration and identity registration. Concerns regarding personal data security. Need for standardization and regulation.
[16] Analysis of IoT and Blockchain Technology for Agricultural Food Supply Chain Transactions	Case studies, like Walmart's pork traceability, are analyzed. It examines IoT integration with blockchain for data transparency.	IoT devices provide empirical data for blockchain applications.Case study: Walmart's pork traceability system demonstrates blockchain effectiveness.	Dependability of data in agricultural traceability systems is a concern.Integration of diverse information systems poses challenges.Need for empirical data to assess economic applications.
[17] A BlockchainBased System for AgriFood Supply Chain Traceability Management	It utilizes Hyperledger Fabric for permissioned blockchain implementation. Smart contracts automate operations related to product quality control. The system allows dynamic adaptation to regulatory changes.It includes a client application for user interaction.	The system mitigates risks of centralized supply chain failures. A prototype was developed using Hyperledger Fabric technology. Two use cases demonstrate the system's effectiveness and features	Centralized systems can become a single point of failure. Transaction throughput limitations in public blockchains. Performance limitations due to sequential transaction processing. Deterministic transactions are challenging to ensure.
[18] Integrated System for Management of Food Supply Chain using Blockchain	Encrypted data blocks linked in chronological order. Users interact via web and mobile applications. Data on farming practices and food conditions is monitored.	Foodborne diseases significantly impact public health in South-East Asia. Integrated platform tracks food quality from producer to consumer. Smart contracts automate data storage	The provided contexts do not mention any limitations of the research paper.
[19]Modeling of Critical Food Supply Chain Drivers Using DEMATEL Method and Blockchain Technology	DEMATEL method identifies causal relationships among drivers. Linguistic scale used for determining relationships and correlations. Average direct relation matrix formed from expert opinions. Total relation matrix calculated for driver ranking.	Results may not reflect the real situation accurately. Future validation needed using other MCDM techniques. Focused only on Indian context, limiting generalizability.	Three critical drivers identified: sustainable food system, food security, pandemic attention. Fourteen drivers analyzed using DEMATEL method for interrelationships. Growing economy creates opportunities for food supply chain investors.
[20] Exploring the Hype of BlockchainAdoption in Agri-Food Supply Chain:A Systematic Literature	A systematic literature review approach was utilized. Twenty-seven full-length articles were analyzed thematically. Qualitative studies were predominantly	Thematic analysis revealed critical areas post-BT adoption in AFSC. Factors affecting BT adoption's impact were systematically gathered. The research	Limited focus on logistics and operational effects of BT adoption. Absence of socio-environmental costing in BT adoption research. Insufficient research on BT adoption in

Review.Agriculture	used in the research	highlighted gaps in BT adoption literature. Future studies should focus on socio environmental impacts post-BT adoption.	developing countries.

III - RESULT

Benefits of Blockchain and Deep Learning in Agro Food Supply Chain

Blockchain technology and deep learning, when used with models like Random Forest, Autoencoder, and LSTM networks, offer significant benefits in the agro-food supply chain like Blockchain Benefits provide first is Traceability and Transparency in which Blockchain provides an immutable and transparent ledger, which ensures that all transactions, from farm to consumer, are recorded in real-time. This helps stakeholders verify the quality, origin, and safety of agro-food products. Second is Reduction of Fraud and Counterfeiting which provide Blockchain technology prevents unauthorized changes to records, thereby reducing fraud and counterfeiting of products. Third is Food Safety and Recall Management which provide Blockchain allows quick identification of contaminated batches, improving response times for recalls and ensuring food safety. Fourth is Smart Contracts for Efficiency which provide automated agreements through smart contracts facilitate transactions, ensuring prompt payment and adherence to predefined terms, reducing manual errors and administrative costs. Fifth is Supply Chain Optimization which provide Blockchain helps optimize supply chain processes by providing better visibility into the flow of goods, minimizing delays, and enhancing coordination.

Deep Learning Benefits with Specific Algorithms like first is Random Forest Model consist Crop Yield Prediction provide The Random Forest model can be used to predict crop yields based on historical data and environmental factors. Accurate yield predictions allow supply chain planning to avoid overproduction or shortages. Quality Classification can classify the quality of agro-food products by analyzing various quality indicators such as size, color, and texture, helping to sort high-quality produce. Disease Prediction in which Random Forest can also detect and classify crop diseases based on historical data, allowing for proactive actions to avoid losses. Second is Autoencoder Model consist of Anomaly Detection in which Autoencoder models can be used to detect anomalies in the supply chain, such as deviations in temperature or humidity levels during storage or transport. Early detection helps maintain product quality and avoid spoilage. Data Compression and Noise Reductionin which Autoencoders are helpful in compressing high-dimensional sensor data while preserving important information. They can also filter out noise, improving the quality of data used for decision-making. Fraud Detection provide Autoencoders can detect unusual patterns in transactions or supply chain activities that may indicate fraud, enhancing transparency.

LSTM (Long Short-Term Memory) Network provide Demand Forecasting in which LSTMs can model time series data to predict future demand for agro-food products. Accurate demand forecasts lead to optimized inventory management, reducing waste and ensuring consistent supply. Supply Chain Disruption Prediction in which LSTMs can analyze historical data to predict disruptions or delays in the supply chain, allowing proactive mitigation strategies to maintain resilience. Price Prediction provide LSTMs can also predict future pricing trends based on historical price data, helping stakeholders make informed decisions on when to buy or sell.

Combined Benefits of blockchain and deep learning contains Blockchain and Random Forest in which Random Forest models can predict optimal harvesting times or potential risks, and blockchain ensures that predictions and resulting decisions are transparent and verifiable. Blockchain and Autoencoder provides Anomalies detected by autoencoders can be logged on the blockchain for secure, traceable records, helping identify the root causes of issues in the supply chain. Blockchain and LSTM Forecasts made by LSTM networks can be used for real-time decision-making, and blockchain ensures that these forecasts are securely shared across the supply chain network.

Together, blockchain and deep learning models like Random Forest, Autoencoders, and LSTM networks improve transparency, enhance decision-making, and optimize efficiency in the agro-food supply chain, ultimately benefiting all stakeholders by reducing losses, improving quality, and ensuring traceability.

Challenges comes in Agro Food Supply Chain

In the agro-food supply chain, several technical challenges arise are Data Quality and Traceability they are Data Fragmentation in which Data across the supply chain is often fragmented, leading to a lack of unified visibility. Different stakeholders use diverse systems, creating issues in tracking and traceability. Data Integrityin which Ensuring that the information is not altered during transmission is a major challenge, affecting food traceability. Sensor Accuracy in which IoT devices used in agriculture for tracking environmental factors might suffer from accuracy issues, leading to poor-quality data collection.

Integration of IoT and Blockchain they are Interoperability in which IoT devices need to seamlessly communicate with blockchain networks for traceability. Lack of standardized protocols across devices hinders integration. Scalability of Blockchain in which Blockchain's inherent limitations in transaction speed and storage requirements can pose a problem when integrating high-frequency IoT data from agro-food supply chains. Data Latency in which Real-time data processing from sensors and devices is necessary for proactive decisions, which can be challenging with blockchain's transaction validation times.

Cold Chain Management they are Temperature Monitoring contains Technical limitations in continuous temperature monitoring during transit can lead to spoilage of perishable goods. Energy Consumption contains IoT-based sensors require power, and maintaining the energy supply during transport is a technical constraint, especially in remote areas.

Information Asymmetry and Trust they are Privacy-Preserving Data Sharing in which Data sharing among supply chain participants raises concerns about privacy. Methods like differential privacy and homomorphic encryption can be complex to implement. Data Authentication in which Verifying the authenticity of data entries, especially for non-digital inputs like farm yields, is challenging in the absence of a robust verification mechanism.

Supply Chain Coordination contains Decentralized Information Sharing in which Agro-food supply chains have multiple stakeholders, including farmers, transporters, retailers, etc. Enabling secure, decentralized information sharing while avoiding central points of failure is challenging. Smart Contracts in which Developing and managing smart contracts for supply chain automation is technically demanding, especially considering the dynamic nature of agricultural conditions (e.g., weather changes affecting crop yield).

Scalability and System Performance contains Throughput Constraints As the number of stakeholders and data transactions increase, the system's ability to handle high transaction volumes without significant delays is limited. High Data Volume in which the agro-food supply chain generates massive amounts of data, from farm sensors to transportation. Processing and storing this data in real-time is a technical challenge.

Interoperability between Systems contains Legacy Systems in which many stakeholders still use traditional, paper-based systems or older software, which makes integration with modern digital solutions difficult. API Standardization Creating standardized APIs for communication between different supply chain systems can be technically complicated, especially when dealing with diverse and siloed data.

Quality Control and Food Safety contains Contaminant Detection in which Implementing automated systems for real-time detection of contaminants or adulterants in food products is challenging, often requiring advanced sensing and AI algorithms. Spoilage Prediction developing predictive models to assess food spoilage requires accurate, real-time data, which may not always be available.

Security and Cyber Risks contains Cyber Attacks on IoT Devices in which IoT devices in agriculture are prone to vulnerabilities such as Distributed Denial of Service (DDoS) attacks, which can disrupt the supply chain. Blockchain Security in which Blockchain networks can be susceptible to attacks like 51% attacks, posing risks to the integrity of the supply chain data.

Sustainability Concerns contains Energy Consumption of Blockchain in which Consensus algorithms like Proof-of-Work consume significant amounts of energy, which is not suitable for a sustainable agro-food supply chain. IoT Device Lifecycle in which Ensuring sustainability in the lifecycle of IoT devices, from production to disposal, is a technical issue that needs to be addressed.

Standards and Regulatory Compliance contains Compliance with Diverse Standards in which Different countries or regions have varied regulatory requirements. Ensuring that the technology complies with all standards is complex. Data Governance establishing data governance frameworks that ensure compliance while allowing transparency is a major challenge in the agro-food supply chain.

Limited Connectivity in Rural Areas contains Network Infrastructure in which Poor connectivity in rural areas where food production takes place can hinder the real-time collection of data and integration with digital supply chain systems. Edge Computing Limitations While edge computing is used to process data locally, its integration with cloud systems for aggregated analysis can be technically difficult due to inconsistent network conditions.

Addressing these challenges requires a combination of technological advancements, infrastructure improvements, and stakeholder collaboration to enhance the efficiency and transparency ofagro-food supply chains.

IV - CONCLUSION

The integration of blockchain technology and deep learning in the agro-food supply chain provides a transformative approach to improving traceability, transparency, and decision-making. Blockchain ensures secure and immutable data sharing across stakeholders, enhancing trust in the supply chain. Meanwhile, deep learning models enable advanced analytics, demand forecasting, and anomaly detection, leading to optimized inventory management and reduced wastage. Together, these technologies address key challenges such as fraud, inefficiencies, and quality control. However, issues like scalability, interoperability, and high implementation costs remain significant barriers to widespread adoption.

V - FUTURE SCOPE

The future development of agro-food supply chains using blockchain and deep learning will focus on the key areas are as follows.

Scalability and Performance Optimization in which Future research should explore methods to enhance the scalability of blockchain networks while maintaining low latency, such as integrating Layer-2 solutions or implementing sharding techniques. These advancements will help accommodate large-scale supply chains with multiple stakeholders.

Interoperability and Integration with IoT in whichfurther work is needed to develop interoperable blockchain solutions that can easily communicate with other blockchain networks and external systems. Integration with IoT devices for real-time data acquisition and edge computing can create more responsive and autonomous supply chain networks.

Federated Learning for Data PrivacyUsing federated learning in combination with blockchain can address privacy concerns associated with data sharing among stakeholders. This approach will enable decentralized model training without direct data exchange, ensuring compliance with data protection regulations.

Cost-Benefit Analysis and Economic Viability in which Future research should investigate the economic feasibility of blockchain implementation in agro-food supply chains, focusing on quantifying the costs and benefits for different stakeholders. The development of lightweight blockchain solutions could make adoption more viable for small-scale farmers.

User Adoption and Smart Contract DesignThere is a need to design more user-friendly blockchain interfaces and smart contracts that cater to stakeholders with limited technical expertise. Future studies should also investigate the socio-technical aspects of user adoption to ensure broad acceptance.

Sustainability and Green Supply Chainthe energy consumption of blockchain networks is a significant concern. Exploring energy-efficient consensus mechanisms, such as Proof-of-Stake or hybrid approaches, could promote the use of blockchain in a more sustainable manner.

AI Integration for Supply Chain Decision-Making Deep learning-based decision support systems for agro-food supply chains can be enhanced with hybrid AI models that integrate reinforcement learning and natural language processing to optimize production, logistics, and demand-supply balance.

Pilot Studies and Real-World Deployments in whichmore pilot projects and case studies are required to validate the effectiveness of blockchain and deep learning solutions in diverse agro-food supply chain scenarios. These real-world deployments will provide insights into the challenges and opportunities associated with scaling these technologies.

By addressing these future directions, blockchain and deep learning technologies have the potential to significantly transform agro-food supply chains, creating a more resilient, efficient, and transparent food production ecosystem.

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