(REVIEW ARTICLE)

Agro-Blockchain Markets (ABM): A secure and transparent model for smallholder farmers

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Abstract

This paper introduces the concept of Agro-Blockchain Markets (ABM), a system that applies blockchain technology to agricultural trade to enhance transparency, fair pricing, and trust among stakeholders. By leveraging blockchain's decentralized, immutable, and transparent nature, ABM enables smallholder farmers to participate in secure and efficient markets, bypassing intermediaries and gaining improved market access. The paper discusses the design and functionality of ABM, highlighting key components such as smart contracts and decentralized exchanges. It also explores the potential benefits for smallholder farmers, including financial inclusion, price stability, and reduced fraud. However, challenges such as technology adoption barriers, infrastructure limitations, and costs are acknowledged. Recommendations for policymakers, agricultural stakeholders, and tech developers are provided, emphasizing the need for supportive regulations, partnerships, and user-friendly blockchain platforms to ensure the successful implementation of ABM. The paper concludes that ABM can significantly empower smallholder farmers and promote sustainable agricultural practices.

Keywords: Agro-Blockchain Markets; Smallholder Farmers; Blockchain Technology; Agricultural Trade; Financial Inclusion; Smart Contracts

1. Introduction

1.1. Introducing the Concept of Agro-Blockchain Markets (ABM)

Agro-Blockchain Markets (ABM) represent an innovative application of blockchain technology specifically tailored for agricultural trade. At their core, these markets utilize blockchain to create secure, transparent, and decentralized trading platforms for smallholder farmers and other stakeholders in the agricultural supply chain (Dosso, Shirazi, & Obaidullah, 2024). The ABM framework aims to address fundamental issues in the agricultural sector by creating an open digital marketplace where transactions can be securely recorded and verified, eliminating the need for intermediaries. In essence, ABM offers a transformative solution for improving the overall transparency, fairness, and trust within agricultural markets. For smallholder farmers, who are often disadvantaged in traditional markets, ABM has the potential to level the playing field by ensuring they receive fair compensation for their products, have direct access to markets, and can trust the integrity of the trade process (Strobel, Castelló Ferrer, & Dorigo, 2020).

Blockchain technology provides the underlying infrastructure for ABM. In this model, blockchain's immutable ledger records all transactions in a decentralized network, meaning that no single entity controls the data, ensuring transparency and accountability. This system replaces the traditional market structures, which are often opaque and

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laden with intermediaries who can distort pricing and capture a disproportionate share of the value. Applying blockchain technology allows ABM to create a more equitable environment where all stakeholders—farmers, buyers, and intermediaries—are subject to the same transparent and verifiable trading conditions (Gupta et al., 2024).

1.2. Significance of Blockchain Technology in Agriculture

Blockchain technology, widely known for its applications in finance and cryptocurrency, is increasingly being adopted in various sectors, including agriculture. The key advantages of blockchain, such as transparency, decentralization, and security, are particularly well-suited to address many of the systemic issues in agricultural trade (Xiong, Dalhaus, Wang, & Huang, 2020). Agriculture, especially in regions dominated by smallholder farmers, often faces challenges related to market access, unfair pricing, fraudulent practices, and lack of trust between producers and buyers. Blockchain's distributed ledger technology ensures that every transaction is recorded in a transparent manner, visible to all participants in the network. This transparency reduces the risk of fraud and builds trust among participants, as they can verify the authenticity and fairness of each transaction (Aldag, 2019).

For smallholder farmers, blockchain represents a significant technological advancement that could revolutionize their participation in local and global markets. Traditionally, these farmers have had to rely on intermediaries or middlemen to sell their produce, which often leads to reduced profit margins and a lack of control over pricing. Blockchain offers a solution by allowing farmers to engage directly with local and international buyers (Kumarathunga, Calheiros, & Ginige, 2022). Smart contracts—self-executing contracts with terms directly written into code—can be employed within ABM to automate and secure transactions. This ensures that once agreed-upon conditions are met, payments are automatically transferred, thus reducing the risk of delayed or unpaid transactions, which is a common issue in traditional agricultural trade (Boogaard, 2018).

1.3. Current Challenges Faced by Smallholder Farmers in Agricultural Trade

Despite their crucial role in global food production, smallholder farmers—who make up a significant proportion of the agricultural workforce—face numerous challenges in accessing fair and transparent markets. One of the primary issues is the lack of transparency in the supply chain, which often results in unfair pricing for agricultural goods (Kos & Kloppenburg, 2019). Many smallholder farmers, especially in developing regions, lack access to reliable market information, making them vulnerable to exploitation by middlemen who take advantage of price disparities. These intermediaries often purchase produce at significantly lower prices and sell it at a higher price to end consumers, capturing a large portion of the value and leaving farmers with minimal returns. This disconnect between production and consumer markets undermines the sustainability of smallholder farming operations (Jayne, Mather, & Mghenyi, 2010).

Another major challenge is the lack of trust between different players in the agricultural supply chain. Farmers, buyers, and consumers may not have access to accurate information regarding the quality and origin of agricultural products, leading to potential disputes or fraud. Without a trustworthy system for verifying transactions, farmers may face delayed payments, unfair trading conditions, or even rejection of their products due to lack of traceability. In many cases, smallholder farmers also suffer from limited market access, as traditional trading mechanisms favor larger agricultural enterprises with more resources, leaving small-scale producers at a disadvantage (Yee, Yeung, & Morris, 2005).

Furthermore, farmers often encounter difficulties in securing fair pricing for their goods due to the dominance of intermediaries in the supply chain. These intermediaries, who connect farmers to larger markets, tend to control much of the pricing dynamics, often taking advantage of information asymmetry. As a result, farmers are frequently unable to negotiate better prices for their produce, leaving them economically vulnerable. Additionally, traditional agricultural markets are often characterized by delayed payment cycles, adding to the financial instability of smallholder farmers. In a sector where liquidity is crucial for sustaining operations and reinvesting in farming practices, these delays can have serious consequences for farmers' livelihoods (Hassoun et al., 2020).

1.4. Purpose and Objectives of the Paper

This paper aims to explore how Agro-Blockchain Markets can address the aforementioned challenges faced by smallholder farmers and provide a sustainable and transparent model for agricultural trade. This paper aims to offer an in-depth examination of the ABM framework, illustrating how blockchain technology can be leveraged to create more equitable market conditions for smallholder farmers. Through the integration of blockchain's decentralized ledger system, ABM has the potential to reduce inefficiencies, ensure fair pricing, and foster trust among stakeholders in the agricultural supply chain.

In addition to outlining the technical components of ABM, this paper will examine the broader implications of adopting blockchain technology in agriculture, including its potential to disrupt traditional market structures and empower smallholder farmers. By eliminating the need for intermediaries and fostering direct interactions between farmers and buyers, ABM can help mitigate many of the challenges associated with current agricultural trade practices. The paper will also explore the potential benefits of ABM in terms of financial inclusion, improved market access, and enhanced security in transactions.

Finally, this paper will provide recommendations for how policymakers, agricultural organizations, and tech developers can collaborate to implement ABM effectively. It will suggest strategies for overcoming barriers to adoption, including education and training initiatives for smallholder farmers and infrastructure development to support the widespread deployment of blockchain technology in agricultural markets. Ultimately, this paper aims to demonstrate how ABM can serve as a viable solution for improving the livelihoods of smallholder farmers and contributing to a more sustainable and equitable agricultural sector.

2. Blockchain Technology in Agriculture

2.1. Overview of Blockchain Technology and Its Key Features

Initially developed as the foundation for cryptocurrencies like Bitcoin, blockchain technology has evolved into a powerful tool for creating secure, transparent, and decentralized systems across various industries. At its core, blockchain is a distributed ledger technology (DLT) that enables data to be recorded and shared across a network of computers, or nodes, to ensure the integrity and immutability of the information (Aviv, Barger, Kofman, & Weisfeld, 2023). This decentralized structure is key to blockchain's value, as it removes the need for a central authority or intermediary to manage or verify transactions (Vaigandla, Karne, Siluveru, & Kesoju, 2023).

One of the defining features of blockchain technology is immutability. Once a block of data is added to the blockchain, it cannot be altered without the consensus of the network participants. This feature ensures that the historical record of transactions remains intact and trustworthy, which is critical in industries where data security and authenticity are paramount, such as agriculture. By guaranteeing that all recorded transactions are immutable, blockchain helps prevent tampering or fraudulent activities, making it highly valuable for sectors reliant on accurate record-keeping (Dong, Abbas, Li, & Kamruzzaman, 2023).

Another important feature of blockchain is decentralization. Traditional systems rely on central entities, like banks or clearinghouses, to verify and facilitate transactions. In contrast, blockchain operates on a peer-to-peer network, where participants validate transactions without the need for intermediaries. This enhances the security and efficiency of transactions and democratizes the system by distributing control among participants. Decentralization ensures that no single entity can dominate or manipulate the system, making blockchain a fairer and more equitable platform for agricultural markets, where smallholder farmers often lack bargaining power (Ibrahimy, Norta, & Normak, 2023).

Transparency is another fundamental characteristic of blockchain technology. Every transaction recorded on a blockchain is visible to all participants in the network, ensuring accountability and reducing the potential for fraud. This openness makes blockchain an ideal solution for industries like agriculture, where supply chain opacity often leads to inefficiencies, corruption, and exploitation. By allowing stakeholders to track every step of a product's journey from farm to market, blockchain fosters trust among participants, including farmers, buyers, and consumers. Transparency is especially valuable in the agricultural sector, where verifying the origin, quality, and handling of products can be difficult and mistrust between stakeholders can undermine market efficiency (Sunmola & Burgess, 2023).

2.2. Blockchain Applications in Agricultural Supply Chains

The agricultural sector is a complex and fragmented industry with a wide array of participants, including farmers, suppliers, processors, distributors, retailers, and consumers. Blockchain technology offers numerous opportunities to streamline and enhance agricultural supply chains by improving traceability, accountability, and efficiency (Caro, Ali, Vecchio, & Giaffreda, 2018). One of the primary ways blockchain can be applied in agriculture is through product traceability. With blockchain, every transaction or movement of goods can be recorded and tracked across the supply chain. From the moment a crop is harvested to the point it reaches the end consumer, each step is documented on the blockchain, creating a secure and transparent record. This traceability is invaluable in ensuring food safety, reducing waste, and enhancing consumer trust (Awan et al., 2021).

Blockchain also plays a crucial role in verifying the authenticity and quality of agricultural products. For instance, organic or fair-trade certifications can be securely recorded on the blockchain, preventing counterfeit claims and ensuring consumers get what they pay for. This level of transparency is particularly important in high-value commodity markets, where fraud and mislabeling are common issues. By providing verifiable proof of a product's origin and handling, blockchain helps protect both producers and consumers from fraudulent practices (van Hilten, Ongena, & Ravesteijn, 2020).

Another important application of blockchain in agriculture is in streamlining payments and contracts. Traditional agricultural markets often involve complex contractual arrangements and delayed payments, especially for smallholder farmers. Blockchain technology can address these issues through the use of smart contracts. These self-executing contracts, written in code, automatically enforce the terms of an agreement when predefined conditions are met. For example, a smart contract could be programmed to release payment to a farmer once the buyer confirms receipt of the goods. This automation eliminates the need for intermediaries and reduces the risk of payment disputes, delays, or fraud. For smallholder farmers, who often face cash flow challenges, receiving timely and guaranteed payments is a significant advantage of blockchain technology (Kshetri, 2021).

2.3. Potential Benefits for Smallholder Farmers

The adoption of blockchain technology in agriculture has the potential to deliver substantial benefits to smallholder farmers, many of whom are marginalized by traditional market structures. One of the most critical benefits is improved traceability. In many agricultural supply chains, products pass through multiple intermediaries before reaching the final consumer, making it difficult for farmers to track where their products end up or how they are priced (Das Nair & Landani, 2020). Blockchain's ability to create an immutable and transparent record of every transaction offers farmers a clear view of the entire supply chain. With this information, farmers can make more informed decisions, negotiate better prices, and ensure that their products are being represented accurately in the marketplace (Chinaka, 2016).

Another key benefit of blockchain is reducing fraud. Smallholder farmers are often vulnerable to fraud, whether it's through dishonest middlemen, inaccurate price reporting, or counterfeit inputs like seeds or fertilizers. Blockchain's transparency and immutability significantly reduce the opportunities for fraud by making every transaction traceable and verifiable. This enhanced security helps build trust between farmers, buyers, and other stakeholders, ultimately creating a more reliable and efficient market environment. Additionally, blockchain can be used to verify the authenticity of agricultural inputs, ensuring that farmers receive high-quality, genuine products, which in turn improves their yields and profitability (Feng, Wang, Duan, Zhang, & Zhang, 2020).

Blockchain technology also plays a crucial role in enhancing trust between smallholder farmers and other market participants. In many agricultural markets, particularly in developing countries, there is a deep-seated mistrust between farmers and buyers due to historical exploitation and a lack of transparency. Blockchain's open and decentralized nature allows all participants to see and verify transactions in real-time, fostering greater trust and collaboration (A.O. Adewusi, N.R. Chiekezie, & N.L. Eyo-Udo, 2022; A.O Adewusi, N.R Chiekezie, & N.L Eyo-Udo, 2022). For instance, a buyer purchasing produce from a smallholder farmer can verify the exact origin and quality of the product, while the farmer can be assured of receiving a fair price and timely payment. This mutual trust is essential for creating more sustainable and equitable agricultural markets (Galvez, Mejuto, & Simal-Gandara, 2018).

Furthermore, blockchain can promote financial inclusion for smallholder farmers, many of whom lack access to traditional banking services or credit. By recording all transactions on a blockchain, farmers can establish a verifiable financial history, which can be used to secure loans or other financial services. This can be particularly beneficial in regions where access to credit is limited, helping farmers invest in better farming practices, equipment, and inputs, thereby improving their productivity and livelihoods (Kumarathunga et al., 2022).

3. Design and Functionality of Agro-Blockchain Markets

3.1. Structure and Operational Model of ABM

The concept of Agro-Blockchain Markets represents a paradigm shift in the way agricultural markets operate, particularly for smallholder farmers. ABM is structured to provide a decentralized platform where all participants in the agricultural supply chain, including farmers, buyers, distributors, and consumers, can interact directly with one another. The core idea behind ABM is to eliminate intermediaries, who often introduce inefficiencies and reduce the profits earned by farmers, especially smallholders. Instead, ABM relies on blockchain technology to facilitate these

interactions, creating a system that is not only secure and transparent but also accessible to all participants (Misra & Ghosh, 2024).

At its foundation, ABM operates on a peer-to-peer (P2P) network. This means that farmers can engage directly with buyers or consumers without having to rely on traditional middlemen, such as wholesalers or agents, who often take a significant cut of the profit (Song, Vajdi, Wang, & Zhou, 2021)s. The decentralized nature of the platform allows for open and direct communication between parties, making the system more efficient and equitable. Additionally, the decentralized structure prevents any single entity from controlling the market, which is a common problem in traditional agricultural markets where power is often concentrated in the hands of a few large players (Roopa, Pradeep, & Kumar, 2022).

The operational model of ABM also includes secure digital wallets for all participants. These wallets are essential for storing digital currencies, such as cryptocurrency, or even tokenized versions of traditional currencies, which can be used for transactions within the platform. Farmers, buyers, and other stakeholders can access their funds and transaction history at any time, providing full transparency over their financial interactions. By digitizing payments and reducing reliance on cash transactions, ABM increases efficiency and reduces the risks of fraud and corruption prevalent in cash-based systems (Song et al., 2021).

3.2. Integration of Blockchain Technology for Secure and Transparent Markets

The integration of blockchain technology into the ABM system is critical for creating a secure and transparent market. Blockchain's decentralized ledger ensures that every transaction made within the ABM platform is recorded in a manner that is immutable and verifiable by all participants. This transparency is crucial in addressing one of the major issues smallholder farmers face: the lack of trust and accountability in traditional agricultural markets (Franklin & Oehmke, 2019). In ABM, every transaction, from the sale of crops to the purchase of agricultural inputs, is logged on the blockchain. Each of these transactions is added to a block of data, which is then verified by the network's participants and added to the chain. Once recorded, these transactions cannot be altered, ensuring that the data is trustworthy and secure. This feature of immutability plays a key role in preventing fraudulent activities, such as altering transaction records or manipulating prices (Ali, Norman, & Azzuhri, 2023).

Moreover, the decentralized nature of blockchain allows participants to verify transactions independently, which is critical for building trust between parties. In traditional markets, the lack of transparency often results in mistrust, especially between smallholder farmers and buyers, who may manipulate prices or withhold payments. In ABM, both buyers and sellers have access to the same transaction data, reducing the likelihood of disputes and ensuring that all parties are treated fairly. This transparency is further enhanced by the fact that all participants, regardless of their size or market power, have equal access to the blockchain, leveling the playing field for smallholder farmers who are often marginalized in traditional market systems (Adebunmi Okechukwu Adewusi, Chikezie, & Eyo-Udo, 2023; Udegbe, Nwankwo, Igwama, & Olaboye).

3.3. Key Components

The functionality of ABM is built on several key components that make the platform efficient, secure, and fair for all participants. One of the most important elements is smart contracts. Smart contracts are self-executing contracts with the terms of the agreement directly written into code. These contracts automatically execute transactions when predefined conditions are met, ensuring that all parties fulfill their obligations without the need for intermediaries (Aiguobarueghian, Adanma, Ogunbiyi, & Solomon, 2024; Kupa, Adanma, Ogunbiyi, & Solomon, 2024). For example, a smart contract between a farmer and a buyer might specify that payment will be automatically transferred to the farmer's digital wallet once the buyer confirms receipt of the goods. This removes the need for trust in a third party, as the contract enforces itself based on the agreed-upon conditions (Roopa et al., 2022).

Smart contracts are particularly beneficial for smallholder farmers, who often face payment delays or disputes in traditional markets. By automating the transaction process, smart contracts reduce the risk of non-payment or delayed payment, which is a significant issue for farmers who rely on timely income to reinvest in their operations (Xiong et al., 2020). Additionally, smart contracts can be customized to include other conditions, such as quality checks or delivery timelines, ensuring that both buyers and sellers are protected and that transactions are carried out in a fair and efficient manner (Ahmadisheykhsarmast, 2020).

Another critical component of ABM is the decentralized exchange (DEX). The DEX allows participants to trade directly with one another without the need for a centralized authority or exchange to facilitate the transaction. This is important in agricultural markets, where central authorities often impose fees or manipulate prices. In a decentralized exchange,

prices are determined by market forces, allowing for more competitive and fair pricing. The DEX also enables the tokenization of assets, meaning that agricultural products can be represented digitally on the blockchain and traded in a secure and transparent manner (Goda, 2020).

The farmer-to-consumer direct transactions are another significant feature of ABM. These direct transactions enable farmers to bypass intermediaries and sell their products directly to consumers or retailers. This increases the farmers' profit margins and ensures that consumers receive fresher and higher-quality products. By cutting out the middlemen, ABM reduces the transaction costs often associated with traditional agricultural markets, making the process more efficient and equitable for farmers and consumers (Thakur, Mehta, & Kumar, 2021).

3.4. Ensuring Fair Pricing and Transparency in Transactions

One of the primary objectives of ABM is to ensure fair pricing for smallholder farmers, who are often exploited in traditional markets. In conventional agricultural supply chains, farmers typically have little control over the prices they receive for their products. Prices are often set by intermediaries or large buyers with disproportionate market power. ABM addresses this issue by allowing farmers to engage directly with buyers, enabling them to negotiate fairer prices based on real-time market data (Ejairu et al., 2024; Uwaga & Nzegbule).

The transparency provided by blockchain technology also plays a crucial role in ensuring fair pricing. Because all transactions are recorded on the blockchain, buyers and sellers can see the prices at which previous transactions were made, reducing the potential for price manipulation. This transparency is especially important in regions where market data is unavailable or farmers are isolated from major markets. With access to real-time pricing information, farmers are empowered to make better decisions about when and where to sell their products, ensuring they receive a fair price (Centobelli, Cerchione, Del Vecchio, Oropallo, & Secundo, 2022).

4. Benefits and Challenges of Agro-Blockchain Markets

4.1. Benefits for Smallholder Farmers

Agro-Blockchain Markets offer significant benefits for smallholder farmers, who are often marginalized in traditional agricultural trade systems. One of the most important benefits is improved market access. In many developing regions, smallholder farmers have limited access to larger markets due to logistical barriers, lack of information, and reliance on intermediaries who take substantial commissions. ABM eliminates these middlemen, enabling farmers to sell their produce directly to buyers, whether they be local consumers or international markets. By bypassing intermediaries, farmers gain more control over the sale of their products and can negotiate better prices, ultimately increasing their profitability (Kimavath).

Another major advantage of ABM is financial inclusion. Many smallholder farmers operate in cash-based economies with little or no access to formal banking systems. This lack of access to financial services can severely limit their ability to grow their businesses, as they cannot easily save, invest, or borrow money (Coronese, Occelli, Lamperti, & Roventini, 2023). With blockchain technology, ABM introduces digital wallets, cryptocurrencies, or tokenized versions of traditional currencies, allowing farmers to store, transfer, and receive payments securely. These wallets enable farmers to participate in a more inclusive financial system, reducing their reliance on cash and minimizing the risk of theft, fraud, or corruption associated with cash transactions. Additionally, blockchain's transparency and security features provide farmers with an immutable record of their transactions, which can help them build a credit history and access loans and other financial products previously unavailable to them (Patel, Shukla, Tanwar, & Singh, 2024).

Price stability is another significant benefit that ABM offers smallholder farmers. In traditional markets, farmers often have little to no control over the prices they receive for their products. Prices are frequently manipulated by buyers or intermediaries, who take advantage of the farmers' lack of market information. Blockchain technology provides real-time, transparent pricing data, allowing farmers to make informed decisions about when and where to sell their products. This increased access to market data helps to stabilize prices, as farmers are no longer subject to the whims of intermediaries. The transparency of the blockchain also ensures that both buyers and sellers can see the historical prices at which goods have been sold, reducing the risk of price manipulation and ensuring a fairer market for all participants (Williams, 2021).

4.2. Challenges of Agro-Blockchain Markets

While ABM offers substantial benefits, several challenges must be addressed for the system to be widely adopted and fully functional. One of the primary challenges is technology adoption barriers. Many smallholder farmers operate in

rural areas with limited access to the internet, electricity, and digital devices, all of which are necessary for using blockchain-based systems. The learning curve associated with blockchain technology can also be steep, especially for farmers who may have low levels of digital literacy. Without proper education and support, these farmers may struggle to adopt and effectively use ABM, preventing them from reaping the platform's benefits (A. O. Adewusi et al.; Udegbe et al.).

Another significant challenge is the cost associated with implementing and maintaining blockchain infrastructure. While blockchain technology itself can offer cost savings by eliminating intermediaries, the initial investment in the necessary infrastructure, such as internet access, digital devices, and blockchain software, can be prohibitively expensive for smallholder farmers, especially in low-income regions. The costs associated with maintaining the system, such as transaction fees and the need for ongoing technical support, could also burden farmers already operating on thin margins (Skaf, 2023).

A related challenge is the need for supporting infrastructure. In many developing countries, the physical and digital infrastructure necessary to support ABM is either underdeveloped or entirely lacking. This includes reliable electricity, internet connectivity, and access to digital devices. Without this infrastructure, it will be difficult for smallholder farmers to participate in blockchain-based markets. Additionally, logistical challenges such as inadequate transportation networks and poor access to storage facilities could limit the effectiveness of ABM, as farmers may struggle to get their products to market in a timely manner, regardless of the digital platform available (Najafi, Kaushal, & Visser, 2024).

4.3. Mitigating Challenges Through Education, Partnerships, and Policy Interventions

To overcome these challenges, several strategies can be implemented. One of the most important solutions is education and training. Smallholder farmers must be provided with the necessary knowledge and skills to adopt and effectively use ABM. This could involve partnering with local governments, non-governmental organizations (NGOs), and agricultural cooperatives to deliver training programs on blockchain technology, digital literacy, and financial management. These programs should be designed to be accessible to farmers with varying levels of education and experience and should focus on practical applications of ABM in their daily operations. By equipping farmers with the tools they need to understand and use blockchain technology, these education initiatives can help bridge the digital divide and ensure that farmers can fully participate in the platform (Mhlanga, 2023).

Another solution is to foster partnerships between the public and private sectors. Governments, NGOs, and private companies can work together to develop the infrastructure needed to support ABM. For example, governments could invest in expanding internet connectivity and electricity access in rural areas, while private companies could provide affordable digital devices and blockchain solutions tailored to the needs of smallholder farmers (A.O Adewusi et al., 2022; Aiguobarueghian et al., 2024). Public-private partnerships could also help subsidize the initial costs of adopting blockchain technology, making it more accessible to smallholder farmers who may not have the financial resources to invest in the necessary infrastructure on their own. These partnerships could also focus on developing user-friendly blockchain platforms that cater to the specific needs of agricultural markets, making it easier for farmers to use the system without needing extensive technical expertise (Udeh, Amajuoyi, Adeusi, & Scott, 2024).

Policy interventions are another crucial way to address the challenges associated with ABM. Governments can play a key role in creating a regulatory environment that supports the adoption of blockchain technology in agriculture. This could involve developing policies that promote financial inclusion, such as providing incentives for digital financial services that cater to smallholder farmers. Additionally, governments could introduce regulations that protect farmers from exploitative practices, such as price manipulation or unfair contract terms, ensuring that blockchain-based markets operate fairly and transparently. Policymakers could also work to create a framework for blockchain-based agricultural markets that ensures data privacy and security, protecting farmers from cyber threats and ensuring that their personal and financial information is secure (Akella, Wibowo, Grandhi, & Mubarak, 2023).

5. Conclusion and Recommendations

In summary, the concept of Agro-Blockchain Markets presents a transformative opportunity for smallholder farmers to overcome long-standing challenges in agricultural trade. By leveraging blockchain technology's immutability, decentralization, and transparency features, ABM can create a more secure and transparent marketplace, ensuring fair pricing and trust among stakeholders. The system enables direct farmer-to-consumer transactions, reduces reliance on intermediaries, and enhances market access, which, in turn, can increase profitability for farmers. Additionally, ABM offers financial inclusion through digital wallets and cryptocurrencies, allowing smallholder farmers to participate in a

modern, inclusive financial ecosystem. However, significant challenges need to be addressed, including technology adoption barriers, infrastructure limitations, and associated costs.

To ensure the successful implementation of ABM, policymakers should prioritize creating an enabling environment for the technology to thrive. This involves investing in digital infrastructure, such as expanding internet access and electricity in rural areas, which is essential for smallholder farmers to utilize blockchain systems effectively. Policymakers should also introduce supportive regulations that ensure fair competition, protect smallholder farmers from exploitation, and encourage financial inclusion by promoting digital payment systems. A regulatory framework that ensures the security and privacy of farmers' data on blockchain platforms should also be developed to increase trust in the system.

Agricultural stakeholders, including cooperatives and NGOs, play a crucial role in supporting the adoption of ABM. These organizations can facilitate education and training programs that help farmers effectively understand and use blockchain technology. Stakeholders can also advocate for partnerships between the public and private sectors to subsidize the costs of digital devices and blockchain infrastructure, ensuring that the technology is accessible to smallholder farmers who may not have the financial means to invest in it independently.

For tech developers, it is essential to create user-friendly blockchain platforms tailored to the needs of smallholder farmers. These platforms should be intuitive and easy to navigate, with minimal technical complexity, to ensure widespread adoption among farmers with varying levels of digital literacy. Developers should also focus on creating affordable, scalable solutions that can be implemented in resource-constrained environments, ensuring that ABM can be deployed in underserved rural areas.

Compliance with ethical standards

Disclosure of Conflict of interest

The authors declare that they do not have any conflict of interest.

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