BLOCKCHAIN-BASED TRACEABILITY IN AGROECOLOGY: LEGAL GOVERNANCE UNDER EUROPEAN UNION LAW

Antonina Zghama
Ph.D. in Law, Assistant Professor, International University, Ukraine
e-mail: zghama@ukr.net, orcid.org/0000-0002-3904-7477

Viktoriia Kachuriner
Ph.D. in International Law, Assistant Professor, International University, Ukraine
e-mail: kachuriner22@gmail.com, orcid.org/0000-0003-2553-5071

Summary

The article examines the legal significance of blockchain-based traceability for agroecological production and agri-food value chains under European Union law. The research is based on the hypothesis that distributed ledger technologies can support agroecological transformation only when they are embedded in a wider framework of data governance, environmental due diligence, organic certification, consumer protection and fundamental rights. The purpose of the article is to identify how blockchain may strengthen the credibility of agroecological claims and, at the same time, what legal limits prevent it from becoming a substitute for public control, certification and accountability. The methodology combines legal analysis of EU regulatory acts, systemic interpretation, comparative assessment of technological and legal functions, and a risk-based approach to digital tools in agriculture. The article argues that blockchain is most useful as an evidentiary infrastructure for recording events, documents and responsibilities across supply chains, especially in organic production, deforestation-free trade and precision agriculture. However, the reliability of such systems depends on the quality of input data, governance of smart contracts, access rights, interoperability, cybersecurity and compliance with data protection law. The study concludes that EU law is moving toward a model in which blockchain may become a technical layer of sustainable agri-food governance, but not an autonomous source of legal truth.

Key words: distributed ledger, sustainable farming, European Green Deal, data governance, supply-chain traceability, organic production, deforestation due diligence, smart contracts.

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1. Introduction

Agroecology has become one of the key intellectual and regulatory responses to the ecological vulnerability of contemporary agriculture. It is not limited to the replacement of one set of inputs with another. Rather, it offers a systemic approach to soil fertility, biodiversity, water quality, climate resilience, animal welfare, local knowledge and fair relations in food systems. In the European Union, this approach is closely connected with the European Green Deal, the Common Agricultural Policy, organic farming rules, the Farm to Fork logic, and the increasing expectation that agri-food products must be not only safe, but also environmentally and socially credible.

The scientific literature emphasises that agroecology should be understood simultaneously as a scientific discipline, a set of farming practices and, in some contexts, a social movement aimed at transforming food systems *(Wezel, Bellon, Doré, Francis, Vallod, David, 2009)*. Agroecology is also defined through the ecology of food systems rather than through isolated farm-level techniques *(Francis et al., 2003)*. This broader understanding is important for legal analysis because traceability in agroecology must cover not only commodity movement, but also ecological processes, institutional responsibility and the credibility of sustainability claims.

At the same time, agri-food value chains are becoming increasingly data-intensive. Farmers, processors, traders, certification bodies, retailers and public authorities generate and exchange information about origin, production methods, pesticide use, soil condition, carbon practices, animal welfare, transport, storage and compliance. The legal and economic value of many sustainable products now depends on whether such information can be trusted. In this context, blockchain, or more broadly distributed ledger technology, is often presented as a tool that can make agri-food supply chains transparent, tamper-resistant and auditable.

The logic of such systems should be viewed through the broader concept of digital transformation. Digitalisation is not merely the conversion of information into electronic form or the automation of existing procedures; it also changes institutional organisation, service models and the distribution of responsibility between human actors and digital tools *(Zghama, 2024: 321-322)*. This observation is important for agroecological traceability because blockchain should not simply reproduce paper-based certification in digital form. It should support a new architecture of interaction between farmers, control bodies, market operators and public authorities.

The scientific problem is that the technological promise of blockchain is frequently stronger than the legal analysis supporting it. A distributed ledger can record that a statement was made at a certain time by a certain participant, but it cannot by itself prove that the statement is true. If incorrect data are entered into the system, the ledger may merely preserve the error more efficiently. Therefore, in agroecological governance, blockchain should be understood not as a replacement for law, inspection or certification, but as a possible evidentiary and coordination layer within a legally regulated system.

The aim of this article is to define the legal role of blockchain-based traceability in agroecology under EU law. The research tasks are: first, to clarify the relationship between agroecological values and traceability; second, to assess the relevance of EU rules on organic production, deforestation-free products, data access and artificial intelligence; third, to identify the risks of blockchain systems in agri-food governance; and fourth, to propose legal principles for the responsible use of blockchain in agroecological supply chains. The study uses general scientific methods of analysis and synthesis, formal legal interpretation, systemic interpretation of EU legislation and a functional assessment of digital technologies in agriculture.

2. Agroecology and Traceability

Traceability is not a purely technical category. In agroecological systems, it performs at least three legal and social functions. The first is evidentiary: it connects a final product with the conditions of production, including land use, inputs, animal welfare, environmental practices and transport. The second is preventive: it makes it easier to identify weak points in a supply chain before violations become systemic. The third is communicative: it allows consumers, public authorities and market actors to distinguish credible sustainability claims from vague environmental marketing.

EU organic policy illustrates this connection. The European Commission describes organic farming as a method that uses natural substances and processes and tends to have a limited environmental impact because it encourages responsible use of energy and natural resources, maintenance of biodiversity, preservation of ecological balances, enhancement of soil fertility and maintenance of water quality *(European Commission, 2026a)*. EU rules also rely on control bodies, certification and regular checks of operators in the organic food chain. This means that legal trust in an organic product is produced not by a label alone, but by an institutional chain of verification.

This institutional understanding is consistent with agroecological scholarship, which treats sustainable food systems as socio-ecological systems rather than merely as production units. The literature shows that agroecology has expanded from plot and field scales to farm, agroecosystem and food-system scales *(Wezel et al., 2009: 503-515)*. Therefore, the legal relevance of traceability is not exhausted by identifying the physical origin of a product; it also includes the capacity to reconstruct decisions, responsibilities and ecological claims across the food chain.

Blockchain can strengthen this chain if it records certification events, laboratory results, transport documents, batch transformations and audit trails in a way that is difficult to alter retrospectively. For example, a cooperative of organic producers may use a distributed ledger to record the certification status of farms, the movement of grain batches from storage to processing, and the link between a final flour package and the relevant production lots. In such a case, blockchain does not certify the product; it preserves and structures the evidence generated by certification and commercial activity.

This distinction is essential for legal clarity. Agroecological claims often concern complex biological and social realities: soil health, biodiversity, reduced chemical dependency, fair treatment of producers, local resilience and climate adaptation. These realities cannot be reduced to a single digital token or quick response code. A blockchain record may point to documents, measurements and responsible actors, but the underlying normative assessment remains a matter of law, science and institutional control.

The legal design of traceability should therefore follow the principle of "qualified transparency". Transparency is qualified when the system makes relevant information visible to the correct actors, at the correct level of detail, and under legally defined conditions. Full public visibility of all agricultural data may harm farmers, reveal commercially sensitive information or expose personal data. Conversely, excessive secrecy may undermine consumer trust and public enforcement. The challenge is to build systems that allow auditability without turning farmers into permanent objects of uncontrolled surveillance.

3. Blockchain in Agri-Food Governance

Blockchain is a type of distributed ledger in which records are maintained across a network and protected through cryptographic methods and consensus mechanisms. In agri-food supply chains, its most relevant features are immutability of recorded entries, shared access to a common data layer, time-stamping, programmable transactions through smart contracts and the possibility of linking digital records to physical goods. These features may reduce information asymmetry between farmers, processors, retailers, regulators and consumers.

Research on blockchain in agriculture generally supports this potential, but with important qualifications. Blockchain is considered promising for transparent food supply chains, while barriers remain in technical maturity, education, policy and regulatory frameworks

(Kamilaris, Fonts, Prenafeta-Boldu, 2019). In food traceability studies, blockchain is also described as a tool that may improve reliability of traceability analysis, provided that data integrity, verification and integration with existing control systems are ensured *(Galvez, Mejuto, Simal-Gandara, 2018)*. Broader reviews of blockchain applications confirm that distributed ledgers create opportunities for traceability and auditability, but also raise unresolved questions of interoperability, governance and implementation design *(Casino, Dasaklis, Patsakis, 2019)*. These findings support the legal argument that blockchain is useful only when it is connected with reliable institutions and enforceable obligations.

The practical value of blockchain in agroecology depends on the type of data recorded. Some data are transactional, such as date of harvest, transfer of ownership, storage location or batch number. Some data are documentary, such as certificates, declarations of conformity, audit reports or laboratory analyses. Some data are sensor-based, such as temperature during transport, soil moisture, satellite observation or equipment performance. Finally, some data are normative, such as whether a product may lawfully be marketed as organic or whether a commodity is deforestation-free. Blockchain is suitable for recording the first three categories, but the fourth category requires legal evaluation.

Smart contracts may automate certain processes, such as releasing payment when a certified delivery is received or notifying a certification body when a prohibited input is recorded. However, smart contracts should not be confused with legal contracts. They execute code according to predefined conditions, while legal responsibility requires interpretation, context, defences, proportionality and remedies. In an agroecological supply chain, the use of a smart contract should be accompanied by conventional contractual clauses defining liability for incorrect data, system failure, cyber incidents, suspension of certification and dispute resolution.

This position is also supported in legal scholarship on blockchain-enabled contracts. Legal contracts should be distinguished from imperative and declarative smart contracts because automated execution does not remove the need for legal interpretation *(Governatori, Idelberger, Milosevic, Riveret, Sartor, Xu, 2018)*. The simplistic idea that "code is law" is criticised in scholarship because smart contracts still require adoption rules, legal remedies and institutional safeguards *(Drummer, Neumann, 2020)*. Smart contracts also require contract-law strategies rather than purely technical treatment *(Filatova, 2020)*. For agroecological traceability, this means that automated compliance tools must remain legally contestable and institutionally supervised.

The problem of legal qualification is especially visible in scholarship on cryptocurrency and virtual assets. The absence of a clear legal regime for decentralised digital assets creates uncertainty for economic activity, taxation, state supervision and liability *(Podtserkovnyi, Reznik, Zghama, Tsurkanu, Kovalevych, 2021: 847-857)*. Although blockchain traceability in agroecology is not identical to cryptocurrency circulation, both fields show the same regulatory challenge: decentralised technologies require legal recognition of roles, assets, transactions and responsible intermediaries.

The EU legal environment is increasingly relevant to this technological architecture. The Data Act became applicable on 12 September 2025 and aims to ensure fair access to and use of data, especially data generated by connected devices. The Commission explicitly notes that business users in agriculture may gain access to data about the performance of industrial equipment and that precision agriculture can use real-time information such as weather, temperature, moisture, market prices and GPS signals to optimise production *(European Commission, 2025a)*. This is directly relevant to blockchain-based agroecological systems because many ledger entries will originate from connected machinery, sensors and digital platforms.

The legal implication is that data generated on farms should not automatically be captured by technology providers or dominant platforms. Farmers need meaningful access, portability and control. If a blockchain traceability system depends on data from tractors, drones, storage sensors or irrigation systems, the allocation of data rights becomes a central issue. Without fair data governance, blockchain may increase dependency on digital intermediaries rather than empower agroecological producers.

Another relevant field is the EU framework for artificial intelligence. Although blockchain and artificial intelligence are different technologies, they are often combined in precision agriculture, risk scoring, predictive maintenance, automated certification checks and supply-chain analytics. The AI Act entered into force on 1 August 2024 and establishes a risk-based framework for AI systems, including transparency obligations and stricter duties for high-risk systems *(European Commission, 2026b)*. Where AI tools are used to evaluate compliance, predict environmental risk or influence access to subsidies and markets, legal safeguards concerning accuracy, documentation, human oversight and non-discrimination become important.

The same conclusion follows from research on digital transformation of justice, where artificial intelligence, blockchain and big data are described as tools that may automate routine tasks and improve access to legal services, but only if infrastructure, ethical standards and cybersecurity are developed in parallel *(Antonina Zghama, 2024: 324-325)*. In agri-food governance, this means that traceability platforms should be assessed not only by technological efficiency, but also by their ability to protect confidential information, preserve procedural fairness and enable effective review of disputed records.

Thus, the future of blockchain in agroecology will not be determined by blockchain law alone. It will be shaped by the interaction of agricultural law, environmental law, data law, consumer protection, contract law, cybersecurity, data protection and AI governance. This interaction is the distinctive feature of the EU approach: digital innovation is allowed and encouraged, but it must operate within a structure of rights, obligations and public purposes.

4. EU Environmental Due Diligence

One of the strongest examples of the convergence between environmental law and traceability is Regulation (EU) 2023/1115 on deforestation-free products. The Regulation aims to reduce greenhouse gas emissions and biodiversity loss by ensuring that products consumed in the EU do not contribute to deforestation or forest degradation. It applies to commodities such as cattle, wood, cocoa, soy, palm oil, coffee, rubber and certain derived products. Operators and traders placing covered commodities on the EU market, or exporting them from it, must be able to prove that the products do not originate from recently deforested land and have not contributed to forest degradation *(European Commission, 2026c)*.

For agroecology, the importance of this Regulation is broader than its list of commodities. It shows that access to the EU market is increasingly connected with environmental due diligence and geographically specific proof. The traditional model of trust based on a general declaration by the seller is being replaced by a model in which legality, land-use history and supply-chain documentation must be demonstrable. Blockchain can help organise such proof by linking farm plots, harvest records, geolocation data, supplier declarations, satellite evidence and due diligence statements.

However, the EUDR also demonstrates the limits of blockchain. A ledger cannot determine whether a forest was degraded, whether a land conversion falls within the legal definition, or whether national land-use rights were respected. These questions require legal definitions, remote sensing, local records, administrative cooperation and enforcement. Blockchain may preserve the chain of custody and reduce the risk of document manipulation, but it cannot replace environmental assessment.

The same logic applies to organic production. Regulation (EU) 2018/848 provides the legal framework for organic production and labelling. The EU system depends on control bodies, certification, inspection and rules for imports. Blockchain may reduce paperwork and improve the traceability of certified goods, but a product becomes organic because it satisfies legal requirements and passes the relevant control process, not because a token has been created for it.

This distinction is crucial for preventing "digital greenwashing". Digital greenwashing occurs when a technological interface gives consumers the impression of ecological credibility without sufficient legal or scientific evidence behind the claim. A QR code on a product may look convincing, but if the underlying data are incomplete, unaudited or controlled by an interested commercial actor, the system may create trust without justification. EU consumer protection law and the broader movement against misleading environmental claims require that sustainability communication be accurate, verifiable and not deceptive.

Therefore, the legally responsible use of blockchain in agroecology should follow several requirements. First, the system must identify who is responsible for each data entry. Second, it must distinguish verified data from self-declared data. Third, it must allow competent authorities and certification bodies to audit relevant records. Fourth, it must protect personal data and commercially sensitive information. Fifth, it must provide mechanisms for correction, because immutability should not mean that false or unlawful data remain practically unchallengeable. A good system does not erase errors silently; it records corrections with reasons, timestamps and responsible persons.

5. Risks and Legal Principles

The first risk is the «oracle problem»: blockchain systems need external sources to connect digital records with real-world events. In agriculture, those sources may be farmers, inspectors, sensors, satellites, laboratories or platform operators. If the external source is wrong, manipulated or biased, the blockchain record will also be unreliable. Legal governance must therefore focus not only on the ledger, but also on the quality, independence and accountability of data sources.

The second risk concerns data protection. Farm data may include personal data when it relates to identifiable farmers, workers, landowners or small family enterprises. Even when data appear technical, they may reveal economic behaviour, location, productivity or personal routines. The General Data Protection Regulation remains relevant where personal data are processed. A blockchain system must define the controller, processor, purposes of processing, lawful basis, retention logic and rights of data subjects. Public blockchains can be especially difficult in this respect because data may be widely replicated and hard to delete. Permissioned or hybrid architectures may therefore be more appropriate for many agroecological use cases.

The third risk is inequality. Small farmers and cooperatives may lack the resources to adopt complex digital traceability tools. If market access increasingly requires digital proof, technology may become a barrier rather than an opportunity. EU policy should avoid a situation in which sustainability becomes visible only when mediated by expensive platforms. Public support, open standards, cooperative models and proportional obligations are necessary to prevent digital exclusion.

The fourth risk is fragmented regulation. Comparative research on cryptocurrency transactions shows that states may classify digital assets differently: as means of payment, property, exchange goods or objects of special financial supervision *(Podtserkovnyi et al., 2021: 847-857)*. A similar problem may arise in agroecological blockchain systems if digital records, tokens, certificates and smart-contract outputs are not clearly connected with recognised legal categories. For this reason, legal design should define whether a blockchain entry is evidence, a certificate, a declaration, a contractual notice or merely technical metadata.

The fifth risk is over-automation. Agroecology values local knowledge, adaptive management and ecological complexity. A system that transforms all compliance decisions into automated binary outputs may fail to capture this complexity. Smart contracts may be useful for routine transactions, but legal and ecological judgement should remain available where facts are contested or values must be balanced. Human oversight is not an obstacle to innovation; it is a condition for legitimate governance.

On this basis, five legal principles may guide blockchain use in agroecological supply chains. The first is legality by design: the system should be built around existing legal categories, including organic certification, due diligence, data access, consumer information and data protection. The second is accountability of inputs: every significant data entry should be attributable to a responsible actor or verified device. The third is proportional transparency: access should be differentiated between consumers, business partners, certification bodies and public authorities. The fourth is interoperability: data should be portable and usable across systems, avoiding technological lock-in. The fifth is contestability: affected actors should have procedures to challenge inaccurate data, unfair automated decisions or misleading sustainability claims.

These principles are consistent with the broader direction of EU digital regulation. The Data Act seeks to improve access to data generated by connected devices and to prevent unfair contractual barriers. The AI Act promotes risk-based accountability, transparency and human oversight. The EUDR requires demonstrable environmental due diligence for covered commodities. Organic legislation relies on certification and controls to protect trust. Together, these instruments point toward a model in which digital technologies must serve sustainable governance rather than replace it.

6. Conclusions

Blockchain can make a meaningful contribution to agroecological governance, but its legal value is conditional. It is strongest when used to record, connect and preserve evidence generated by legally recognised actors: farmers, cooperatives, certification bodies, laboratories, logistics providers and competent authorities. It is weakest when presented as a self-sufficient guarantee of ecological truth. Agroecology is a complex normative and scientific field; no ledger can replace soil assessment, biodiversity monitoring, public enforcement or responsible certification.

Under EU law, the most promising function of blockchain is to support trustworthy traceability in sustainable agri-food systems. In organic production, it may help connect certificates, batches and audit trails. Under the EUDR, it may organise supply-chain evidence and due diligence documentation. Under the Data Act, it may interact with connected agricultural devices while strengthening farmers' access to data. In AI-supported precision agriculture, it may provide logging and traceability that contribute to accountability. These functions are valuable precisely because they are embedded in law.

At the same time, blockchain-based systems must address risks of incorrect input data, digital greenwashing, personal data exposure, technological dependency and exclusion of small producers. The EU approach suggests that innovation should be combined with legality by design, accountability, proportional transparency, interoperability and contestability. Future research should focus on practical governance models for cooperative and public-interest blockchain infrastructures in agriculture, including standard contractual clauses, certification interfaces and mechanisms for correcting erroneous ledger records.

The central conclusion is that blockchain should be treated as an institutional technology rather than merely a technical instrument. Its success in agroecology will depend less on the sophistication of cryptography than on the quality of legal design, public oversight and trust relations among actors in the food system. In this sense, blockchain may become useful for agroecology only when it remains subordinate to the ecological and legal purposes that justify its use.

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