

TRUSTyFOOD

**R&I Roadmap for blockchain technologies
in the Agri-food sector**



Funded by
the European Union

TRUSTyFOOD consortium

Tecnoalimenti S.C.p.A.

Centre for Research and Technology – Hellas (CERTH)

- Institute for Bio-Economy and Agri-Technology (iBO)
- Information Technologies Institute (ITI)

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Confederazione Generale dell'Agricoltura Italiana (Confagricoltura)

North-South Consultants Exchange LLC (NSCE)

Compellio SA

World Farmers' Organisation (WFO)

TRUSTyFOOD

R&I Roadmap for blockchain technologies in the Agri-food sector



September 2025

DISCLAIMER

This is the result of a study conducted in the framework of TRUSTyFOOD project, collecting and cross-matching numerous views and opinions from external stakeholders. The views expressed do not necessarily reflect those of the publishing organizations, nor the official position of their employers.

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Executive Summary

This Roadmap provides the European Commission with evidence-based guidance on how to strategically invest in blockchain Research and Innovation within the agri-food sector to quickly solve existing challenges and move towards a more secure, sustainable, and equitable global food system based on blockchain technology. This roadmap represents a mature, evidence-based approach based on 36 months of work carried out using different means: desk research, surveys, interviews and co-creation workshops at the basis of International working-groups, local focus groups and task forces. 13 participants in the TRUSTyFOOD consortium and about 200 external stakeholders from 19 countries contributed to the achievement of this strategic output.

The document confirms that BCT application in agri-food is at an early adoption,

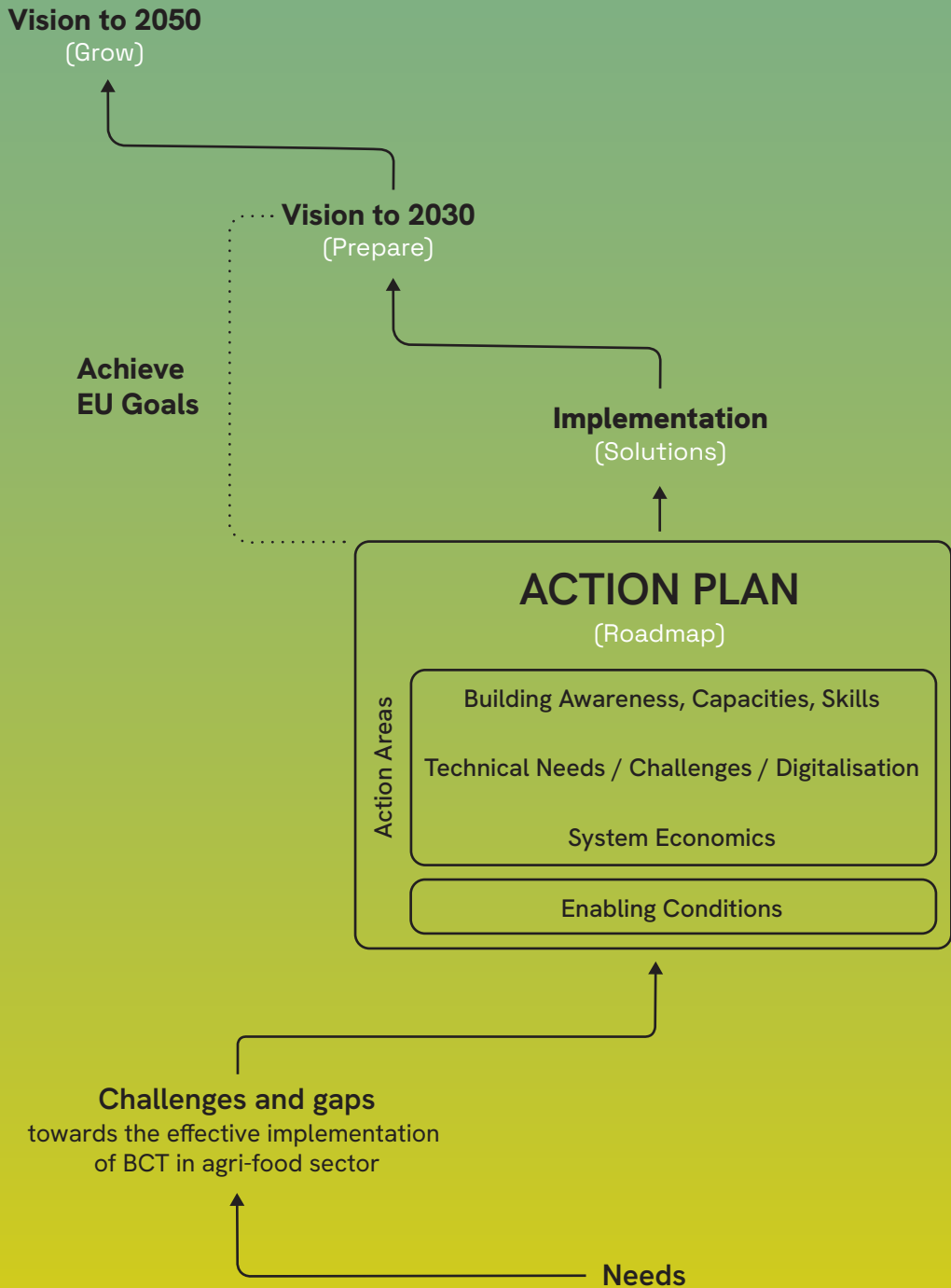
analysing the reasons behind its low widespread use along the agri-food system, identifying the factors which contributed to its refusal or in a failure to move from the pilot stage to the production stage. It analyses the potential benefits behind it as well as the current challenges, while proposing the solutions co-created with external stakeholders to overcome them.

The document envisions three possible futures of the EU food systems and a portfolio of R&I priorities, to prepare the way for R&I activities for the decade to come. Some recommendations are included at the end of the document, mainly addressed to EC decision-makers, Member State governments developing national blockchain strategies, Industry stakeholders planning technology investments and Research organizations identifying priority research areas.

36
months
of work

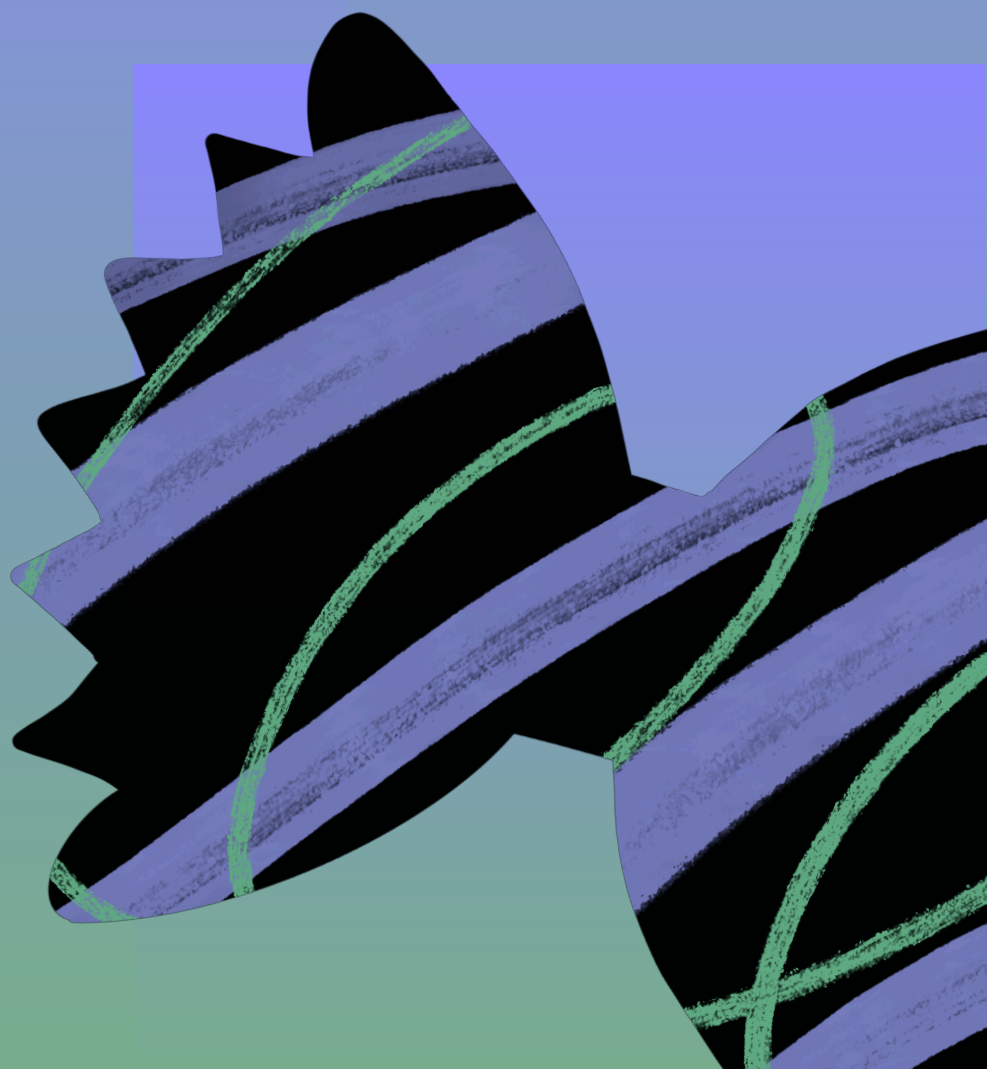
200
external
stakeholders

Approach of the EU Roadmap to 2030 for R&I on BCT



First
Part

Introduction



01

Objective of the Roadmap

The **EU Blockchain strategy**¹ launched in early 2018 by the European Commission aims to make EU a major innovator in blockchain through three levels of actions: EXPLORING - CONNECTING - SUPPORTING.

The TRUSTyFOOD project intervened at two levels, i.e.: Exploring (more details in chapter 3 and chapter 6) and Supporting, through the preparation of this **R&I Roadmap**. It provides the European Commission with evidence-based guidance on how to strategically invest in blockchain research and innovation within the **agri-food sector** to quickly solve existing challenges and move towards a more secure, sustainable, and equitable global food system.

This roadmap represents a mature, evidence-based approach to blockchain in agri-food, and moving beyond hype cycles and technology-driven solutions to focus on research and innovation priorities that address real stakeholder needs and account stakeholder interests in a global perspective. It provides **practical guidance on where and how to invest EU resources** to maximize impact for European agriculture and food systems. Crucially, this roadmap positions blockchain as an enabler of agri-food transformation rather than an end in itself; it focuses on solving real agricultural challenges through appropriate technology application, not pursuing technology for its own sake.

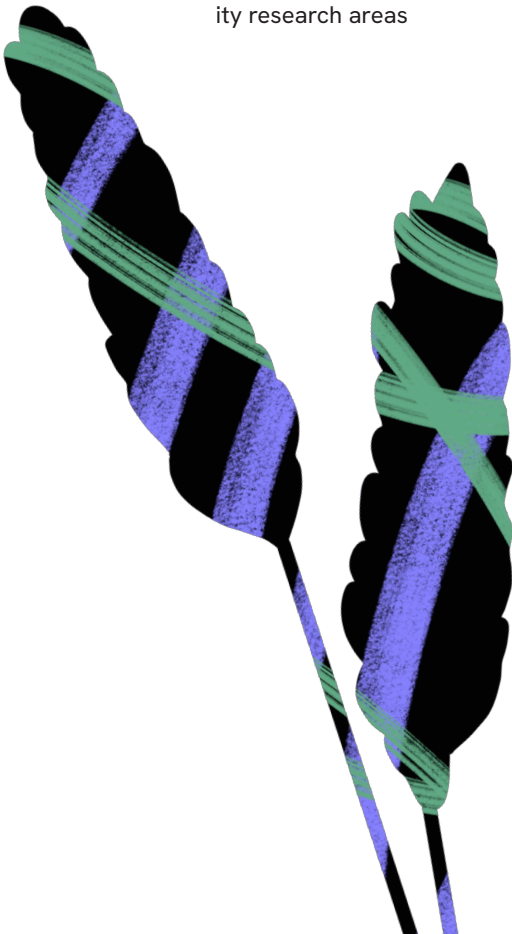
¹ <https://digital-strategy.ec.europa.eu/en/library/european-blockchain-strategy-brochure>

02

Target audience

While primarily designed for EC decision-makers, this roadmap serves as a strategic reference for:

- Member State governments developing national blockchain strategies
- Industry stakeholders planning technology investments
- Research organizations identifying priority research areas
- National Farmers Organisations (the scalable, and structured way to engage farmers collectively, ensuring their voices shape decisions and solutions that work on the ground)



03

Methodology

The R&I Roadmap is the final output of a long process which lasted 36 months. The project started with an exhaustive “**desk research**” necessary to define the State-of-the-Art (SoA). Such phase lasted 12 months and was divided into three complementary and interactive stages.

The **first stage** focused on a systematic status **analysis of peer-review publications**, existing databases, library of papers, articles, and other qualified digital resources related to the use of BCT in the agri-food context. We generically refer to it as “literature”. That allowed the project to identify techniques and applications but also a range of promising conceptual BC-related innovations potentially able to enable and reshape the food system.

A **second stage** foresaw the identification of **existing pilots/use-cases**² that have been deployed either as part of private initiatives, European projects or national projects and **their in-depth analysis**. The **third stage** involved cross-matching the information collected in the previous two stages to **generate preliminary findings**.

The second part of the project, which lasted two years, was based on **co-creation and stakeholders’ engagement methodologies**. It aimed at engaging stakeholders and gathering information, confirmations and insights from them, to co-create strategies and recommendations for the R&I Roadmap.

Table 1

Stakeholder Group 1	Farmers and associated actors
Stakeholder Group 2	Agrifood sector actors
Stakeholder Group 3	NGOs, civil society, and SSH researchers
Stakeholder Group 4	BCT experts and STEM researchers
Stakeholder Group 5	Polymakers

² Use case: intended as applicative case of blockchain technology in an operational scenario (integrating it in on-going activities/procedures/processes) to test its performances and decide if to move towards a full-scale application.

Among the numerous techniques for collecting information and interacting with stakeholders, the Consortium applied the following ones:

Table 2

TECHNIQUE	ADVANTAGES
Surveys	Gather baseline data
Interviews	Solicit stakeholders in expressing views and opinions Enable stakeholders to speak freely and confidentially about controversial and sensitive issues Build personal relations with stakeholders
Working groups (WGs) Task Forces (TFs)	Allow the group of stakeholders to provide their views and opinions Create a Network of stakeholders and relations among them
Focus groups	Allow a smaller group of people to provide their views and opinions of targeted baseline information Complement the picture that emerge at a generic level including peculiarities and nuances at local level

Desk research, surveys and Interviews, Working Groups, Focus Groups and Task Forces contributed together to the definition of the R&I Roadmap’s priorities and contents.

Understanding blockchain application at global level

The work done has primarily focused on Europe. However, understanding and examining blockchain application at global level is essential, both because of the increasing complexity and globalization of the agri-food supply chains and because valuable insights for future European applications can be drawn from cases beyond its border.

For this reason, desk research and the insights was not limited to Europe only.

TRUSTyFOOD involved into the consortium the World Farmers Organisation (WFO), a member-driven international organisation of national farmers’ organisations and agricultural cooperatives from across all continents acting at Global level, and North South Consultants Exchange (NSCE) acting in the MENA region and Africa. Both actively contributed to desk research, use cases collection and analyses, and engaging representatives of national farmers organisations and stakeholders from such countries for WGs and focus groups.

Some numbers of the conducted work

12

Months of
Systematic Research

320

N. of
Collected Use Cases

93

N. of Face-to-face
and Phone Interviews

97

N. of
Surveys Received

4

N. of
Focus Groups

26

N. of Participants
to Focus groups

13

N. of WGs workshops
(Phases 1, 2, 3, 4)

3

N. of
Task Forces

20

Experts involved
in Task Forces

>300

N. of
Papers consulted

141

 from 19
countries

Total number of
Stakeholders attending WGs

Second
Part

Understanding the context



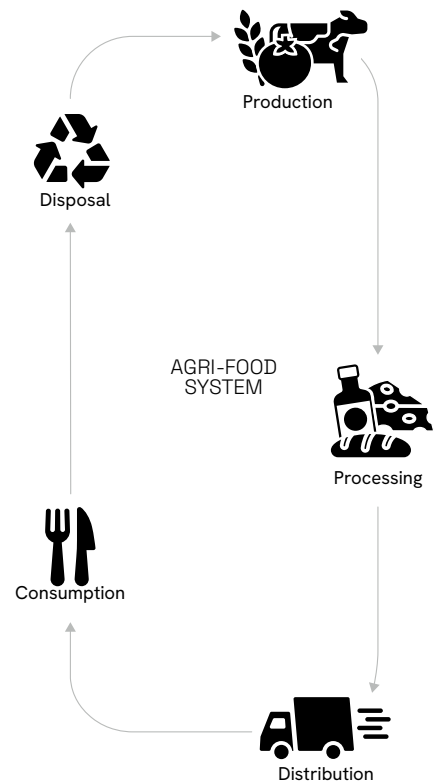
04

The sector of application

The **agri-food system** is complex. It's **not just about farming**; it involves a chain of activities from primary agricultural production to the final consumption and disposal of food and other related products. A wide range of actors with potentially conflicting interests operate within the agri-food system, including farmers (crop farmers, livestock farmers, fishermen, aquaculture operators), food and drink industry, distributors, retailers, and consumers. It also encompasses suppliers of inputs and services (seeds, pesticides, fertilisers, machinery, packaging, repair, transport, finance, advice and logistics), and public control authorities.

Supply chains can be broadly categorized into short, conventional (or long), and global chains, each with distinct characteristics and implications for sustainability, efficiency, and consumer experience. Short food supply chains (SFSCs) emphasize direct or near-direct relationships between producers and consumers, often with fewer intermediaries and a focus on local sourcing. Conventional or long supply chains involve multiple intermediaries and often span larger geographical areas, while global supply chains extend across international borders, potentially involving complex networks and diverse transportation methods^{3,4}.

Considering the complexity of the agri-food sector and all the actors involved is crucial for developing effective policies and strategies to address challenges related to food security, safety, sustainability, and resilience and exploit the full potential behind this new emerging technology.



³ <https://www.fda.gov/food/new-era-smarter-food-safety>

⁴ <https://www.who.int/news-room/fact-sheets/detail/food-safety>

05

Introducing blockchain technology

Blockchain technology, often heard in discussions about digital currencies, is much more than that. At its core, it is a revolutionary way of immutably recording, sharing, and verifying information.

Imagine a digital notebook where everyone involved has an identical copy, and every new entry is immediately shared and verified by everyone.

This “notebook” has three key features:

- **Immutability:** once something is written into this digital notebook, it makes it hard to change or erase it without all stakeholders noticing. Each new entry is cryptographically linked to the previous one, forming a “chain” of records. Think of it like a permanent ink; once written, it is there forever. This makes the information incredibly trustworthy because you know it has not been tampered with.
- **Decentralization:** unlike traditional systems where one central authority (like a bank or a government agency) controls all the information, blockchain is a Key Enabling Technology for the goal of decentralization.

- **Distributed Ledger** (shared records): every participant in the blockchain network has their own identical copy of the entire digital notebook (the “ledger”). When a new entry is made, it is broadcast to everyone, and all copies are eventually updated. This ensures transparency and eliminates the need for intermediaries to verify transactions, as everyone has access to the same, verifiable record.

These technical features allow the system to run services which can automate processes, like **smart contracts**. A smart contract⁵ represents a computer program that runs on a blockchain. Despite their legal connotation, their legal enforceability is still being discussed.

Smart contracts are used to build decentralized applications (dApps) that can be used for automatic actions such as payment when predefined conditions are met (e.g. delivery arrived).

Because they run on a blockchain, i.e. a decentralized computer network, the contract is executed by all the participants within the blockchain network to maintain the same and shared state.

⁵ <https://ethereum.org/en/developers/docs/smart-contracts/> - <https://ethereum.org/en/developers/docs/dapps/>
https://www.cigionline.org/static/documents/no.271_UN5GG6q.pdf

BLOCKCHAIN TECHNOLOGY**01****Immutability**

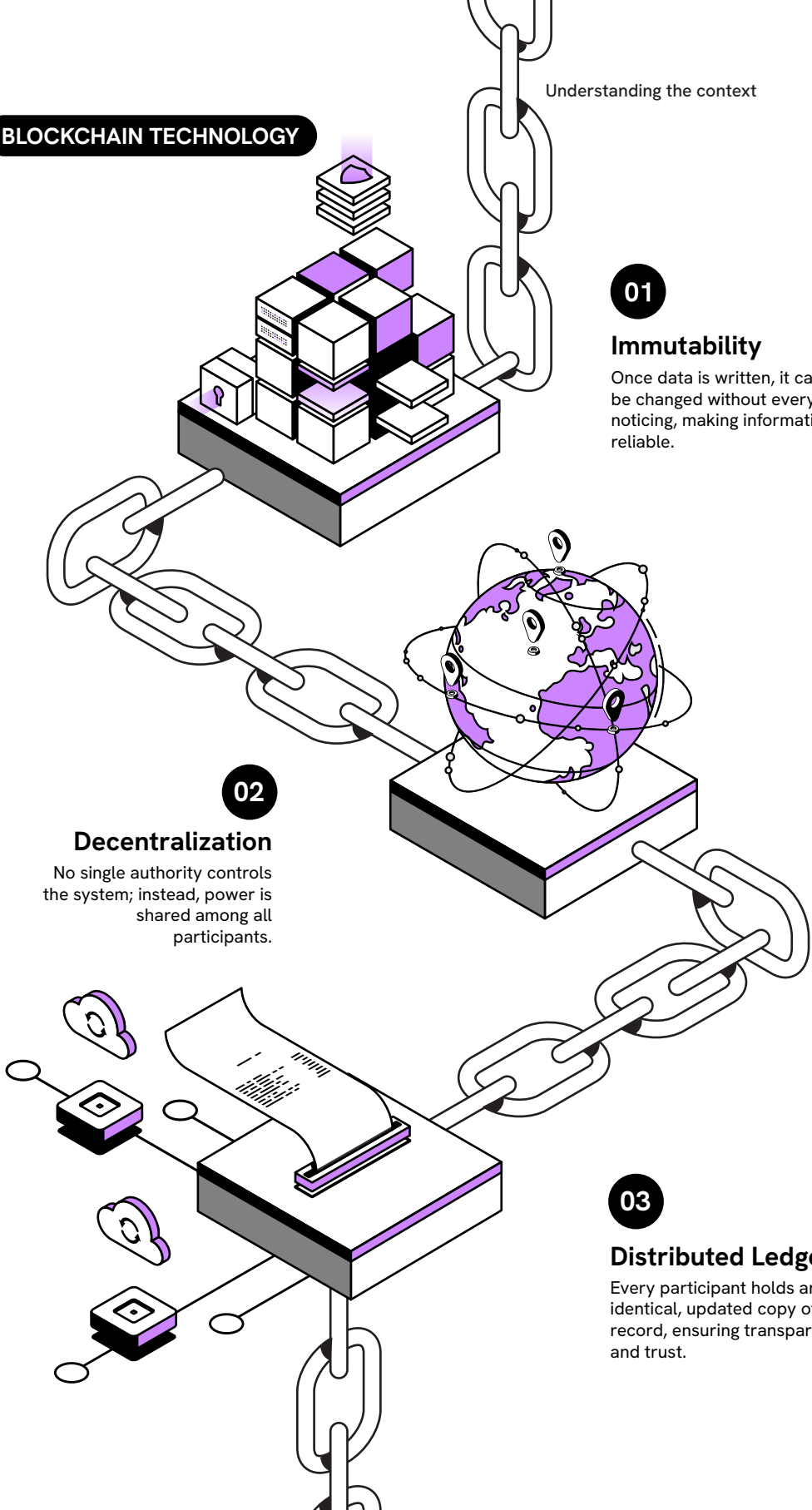
Once data is written, it cannot be changed without everyone noticing, making information reliable.

02**Decentralization**

No single authority controls the system; instead, power is shared among all participants.

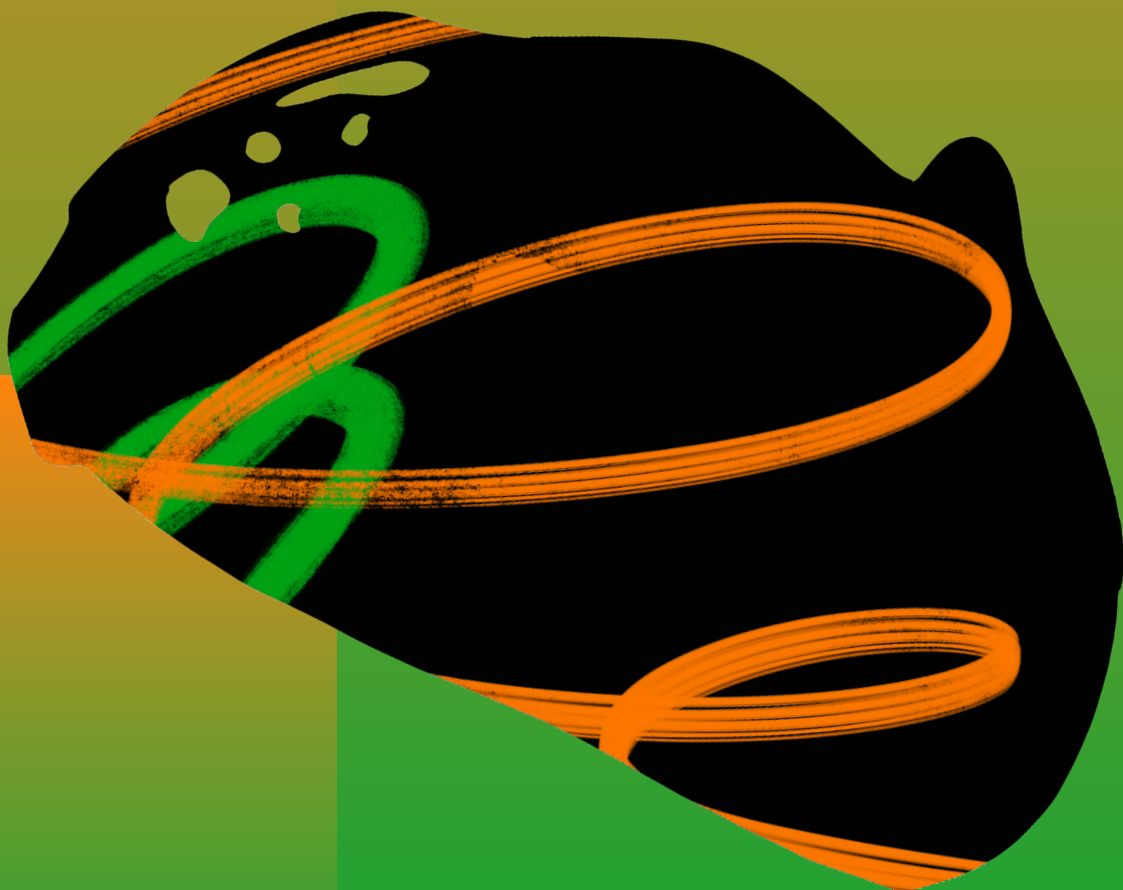
03**Distributed Ledger**

Every participant holds an identical, updated copy of the record, ensuring transparency and trust.



Third
Part

Lessons learned



06

Where Europe stands today: the diffusion of Blockchain Technology in the agri-food system

20-28%

European market share

320

use cases mapped and collected

Different reports state that while some EU countries are actively pursuing blockchain solutions, much of the activity as pioneers is concentrated outside Europe. According to recent data⁶, Asia-Pacific is leading with nearly 40% share, follow North-America and Europe, while Middle-East and Africa cover only 5%.

The exact number of companies using blockchain in Europe's agri-food sector isn't readily available. **Its adoption is still in the early stages⁷** and in some countries (e.g. Italy) market evolution in the period 2022-2024 is at a standstill⁸ reflecting the lack of investments in medium-long terms.

TRUSTyFOOD research followed a methodical process, starting with the collection of raw data from various sources and continuing with the data cleaning stage. Out of the 320 use cases mapped and collected, the situation in the EU and developing countries was examined in depth. The valuable contribution of WFO and NSCE through direct contacts with own members or local stakeholders confirmed the small number of use cases in Middle East and Africa.

147 use cases related to the EU and agri-food sector have been further analysed and related findings reported below.

⁶ <https://www.marketresearchfuture.com/reports/blockchain-in-agriculture-and-food-supply-chain-market-31200>

⁷ Mohapatra, Soumya, et al. "Application of blockchain technology in the agri-food system: a systematic bibliometric visualization analysis and policy imperatives." *Journal of Agribusiness in Developing and Emerging Economies* 15.2 (2025): 288-310.

⁸ www.osservatori.net

6.1. Blockchain EU use cases: some findings

6.1.1. The enterprises engagement process

Academic and industrial literature, together with TRUSTyFOOD surveys, interviews and working group discussions, demonstrate that, over the past few years, the promotion of blockchain technology (BCT) within the agri-food sector has primarily been driven by technology providers who designed their own solutions and actively sought out clients. Their focus largely remained on larger or medium-sized food producers, whose scale, resources, and digital readiness made them easier to approach. This emphasis was understandable from a business perspective, as these enterprises had the financial and organizational capacity to experiment with complex, high-cost innovations. Gradually, small food producers started to be approached as well.

Farmers were mostly reached via funded initiatives—often as grant recipients or experimental partners in pilot projects—rather than through commercial channels. Publicly led or donor-backed programs brought blockchain solutions also to rural actors.

6.1.2. The source of investment

The support of public funds has been used by about half of the use cases.

6.1.3. The level of technological maturity of BCT applications

Systematic reviews in literature affirm that a significant portion of European blockchain applications are still experimental (at a con-

cept – prototype or pilot level), with limited full-scale implementations⁹.

TRUSTyFOOD consortium searched a way to confirm such data. As the maturity level¹⁰ of blockchain applications was an information not directly declared by use cases and a fine-grained differentiation was not possible to achieve without substantial effort and high risk of failure, a methodology to classify them was implemented by Fraunhofer Institute.

Starting from data publicly available (online, Interviews, surveys), the methodology was based on the Technology Readiness Level (TRL) framework that has been used in EU funded projects since 2014 as part of the Horizon 2020 research and innovation funding program.

Adaptations to the TRL were done for our work grouping together under following categories:

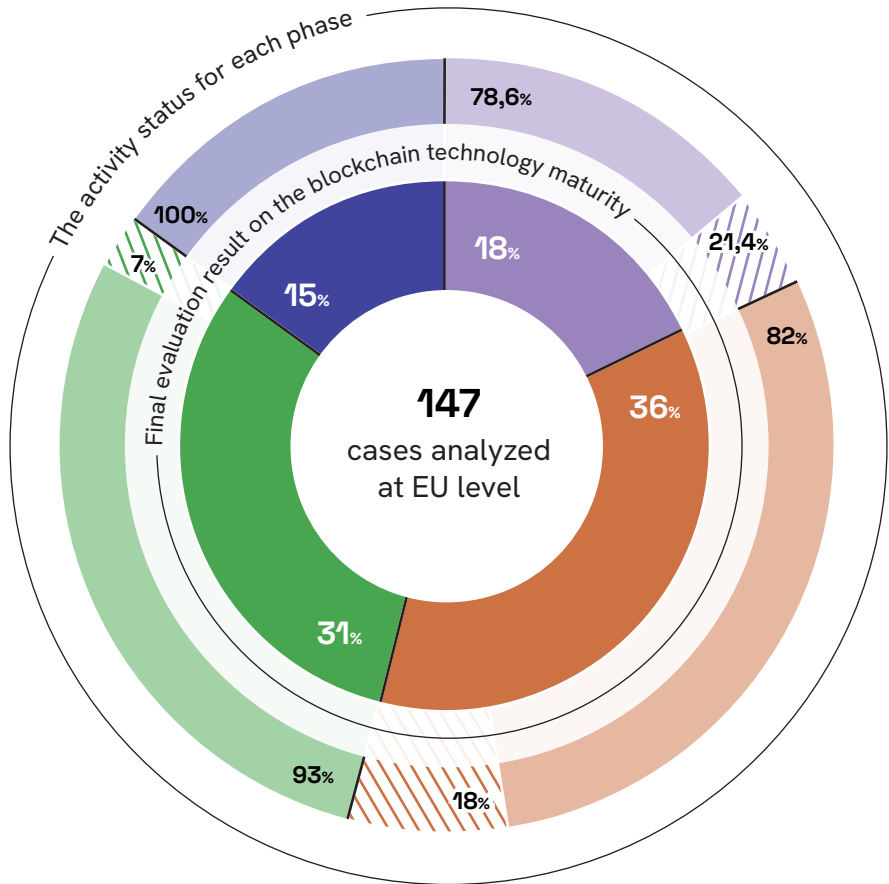
1. TRL 1-2 = Concept (theoretical and experimental)
2. TRL 3-4 = Prototype (implementation in isolated environment)
3. TRL 5-7 = Pilot (implementation in real environment)
4. TRL 8-9 = Production (fully working product in operational environment)

For the categorization of each use case, criteria based on the TRL framework and blockchain-specific evaluation criteria were taken into consideration.

⁹ O. Labazova, T. Dehling, A. Sunyaev, From hype to reality: A taxonomy of blockchain applications - Paper presented at the proceedings of the 52nd Hawaii international conference on system sciences (HICSS 2019).

¹⁰ Intended as how advanced they are in being implemented even though they share the same underlying technology.

PHASE	CHARACTERISTIC	TRL EQUIVALENCE	EVALUATION CRITERIA
CONCEPT	Theoretical & Experimental	1 & 2	Mainly based on theory, concept clearly explained, scientific research just started Tests are designed and have to be conducted based on the initial findings Technical details listed, including blockchain platform and consensus mechanism, however technology still very speculative
PROTOTYPE	Implementation in isolated environment ("laboratory")	3 & 4	Tests/experiments were conducted which support initial findings Proof-of-concept model constructed (private) Technology is feasible from scientific point of view Basic technology implemented together in isolated environment/laboratory to show they work together Data published on the technology, either through open-source code platforms, transaction data, or through published data (on website)
PILOT	Prototype implementation in industry-relevant or operational environment	5, 6 & 7	Solution now tested in environment, which is closer to real one (although still under controlled conditions) → Technological feasibility proven 2+ partnerships with external companies announced. The pre-condition is, that the organization has already proven their use case internally before collaborating with others Solution now tested in real environment → Engineering feasibility proven Media reports or public data released of partner PoC or pilot successfully using the technology Proof of use in an operational supply chain as opposed to using a test environment
PRODUCTION	System complete, implementation in operational environment and full integration with existing systems	8 & 9	Implementation and integration of new technology in its final form with existing technology Stable version of software available New technology after integration can operate under full commercial deployment If produced, the planned product roadmap is completed Security and quality have been verified by third parties If possible, all code is publicly available in open-source projects and functional Blockchain technology is fully integrated into the system and operating competitively to other projects



■ Concept ■ Prototype ■ Pilot ■ Production
■ Active (solid color) ■ Inactive

15%

reached the production stage

Figure above shows the final evaluation result on the blockchain technology maturity of 147 cases analyzed at EU level. The technology is still being actively explored with 36% showing characteristics of a prototype followed by 31% in the pilot phase, which test the solution under conditions that are similar to the real world. 18% fall into the 'concept' phase and it shall be noted that research projects, despite their complexity and involvement of other partners, tend to

fall into that category as the project goal does usually not require the development of a working product. **Only around 15% seem to have reached the production stage.** Figure looks at each phase and their activity status. 21,4% of concept cases, 18% of the prototype cases and 7% of pilot cases are inactive. Regarding the production cases, all are still active confirming that increased maturity correlates with a reduced likelihood of failure.

6.1.4. The EU countries most active in BCT

35%

of the analyzed activity comes from Italy's private sector

From our analysis on 147 use cases, Italy has the strongest private-sector and industry-driven activity (35%) — Such leadership could be justified by the country's need to safeguard and promote Made in Italy products as well as combat Italian Sounding - Italy has hundreds of PDO (Protected Designation of Origin) and PGI (Protected Geographical Indication) products, which depend heavily on brand protection and consumer trust, which blockchain traceability directly supports.

In second position we find France (11%), one of the Europe's largest agricultural producer, with a wide range of products from dairy and wine to cereals and meat—making it fertile ground for supply chain innovation, and with strong retail-driven Blockchain Adoption (Carrefour, Auchan, and Intermarché). Follow the Netherlands (strong institutional support and startup ecosystem), Germany (it has a strong export-oriented food industry, and blockchain

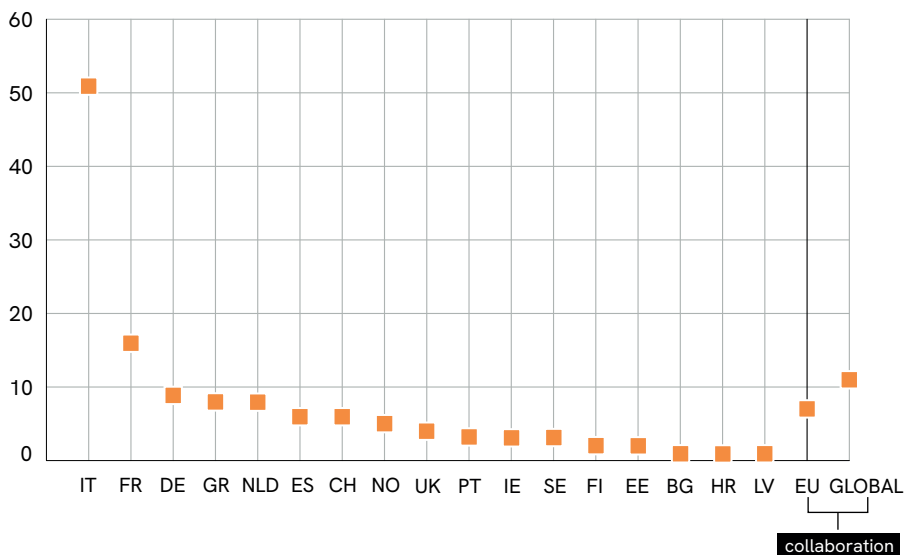
is being tested to ensure compliance with traceability regulations), and Greece which has launched multiple blockchain demonstrators focused on geographic origin and authenticity. Portugal/Spain are emerging with retail grocery pilots via TE FOOD in produce chains.

When blockchain is tested through public funds, EU actors act in consortia involving other EU countries or at global level; most BCT-powered agri-food initiatives have a scope that reaches beyond Europe.

6.1.5. The food sectors mostly involved

Blockchain technology is being increasingly piloted across various food sectors. Among the most frequently targeted categories are wine, olive oils, dairy products, specialty coffee, meat and poultry, seafood, fresh produce—including fruits and leafy greens, and multi-ingredient and value-added food products—such as packaged baby foods, salads, organic produce, and PDO/PGI-labelled items.

USE CASES PER COUNTRY



6.1.6. What prevents the adoption

The low level of adoption in the sector is in part the consequence of a widespread refusal among farmers and producers of the technology. Working groups and local focus groups clarified that behind such behaviour there is a lack of awareness and knowledge. Many smaller agri-food actors lack robust ICT infrastructure, digital literacy, or sufficient management capacity to explore unfamiliar systems. Often BCT is seen as a “technology for the few”—perceived as too complex, too costly, and too disconnected from day to day operations in small-scale agriculture. Many small players simply do not see the advantages—whether in traceability, market access, consumer trust, or environmental compliance—as outweighing the effort required to onboard onto these platforms.

6.1.7. Why numerous piloted use cases failed

Among organizations that adopted blockchain, failures in moving from pilots to full-scale implementation phase contributed to mark the low level of BCT adoption to date. Through our analysis the following reasons have been identified:

1. Lack of clear objectives and use-case

Academic literature, surveys, interviews and working-groups consistently identified the misalignment between the motivations of technology providers and the priorities of smaller agri-food actors as one of the main reasons for failure in pilots’ scale up. A tech-first approach as opposed to a needs-based did not repay. Indeed, it has not been uncommon for enterprises to jump on the blockchain bandwagon without having a clearly defined problem they were trying to solve. When a project was driven solely by the hype surrounding the technology without clarifying what specific issue the

technology would address, it was likely to devolve into a directionless endeavor, eventually leading to its failure.

2. Poor understanding of blockchain technology

Understanding the limitations and advantages of blockchain is crucial for its successful application. Many enterprises mistakenly view blockchain as a one-size-fits-all solution. This misunderstanding often led to poor application of the technology, or to uncertainty over how requirements interact with the application and underlying ledger. Let’s make clarity on this. Blockchain needs “data bridges” or blockchain oracles (which act as trusted data carriers) to bring data from the “real world” on the blockchain.

Also blockchain is not good at storing large amounts of data and stores only specific types of data—mainly transactional records or state changes. The strength of blockchain is rather on verification (i.e. to not rely on trust only but also to cryptographically check, whether what has been said by others in the blockchain network is also true for me). The main goal of blockchain is ensuring data integrity (every computer has the same data and agrees on them). So, blockchain could check that the data comes from a specific IoT sensor through verifying the digital identity of the sensor, but blockchain is not necessarily good at storing the data generated by the tool if such data is large in size.

3. The technological complexity and rigidity

Yet, technical limitations, such as scalability issues, interoperability gaps, and data privacy concerns, posed significant barriers in pilot implementations. These obstacles are exacerbated by a lack of shared standards and governance models, making integration across different blockchain platforms and legacy systems difficult to achieve.

Also, blockchain and smart contracts introduce excessive rigidity in the financial and/or methodological management of processes, which today are managed in a flexible manner with non-codified agreements between the parties; such reason often made companies give up on a full-scale implementation.

4. Regulatory and compliance issues

Blockchain's decentralized nature often conflicts with existing regulations like GDPR and various data sovereignty laws.

5. Costs and uncertain return on investment (ROI)

The initial implementation can be quite resource-intensive and the uncertain returns have discouraged further adoption from numerous enterprises, especially where immediate operational pressures take

precedence over long-term innovation. The future costs—both fixed and ongoing—look unjustifiable when the expected returns remain ambiguous or distant.

6. Inadequate stakeholder buy-in

For a blockchain project to succeed, it needs to be embraced by all stakeholders involved—this includes management, IT departments, business units, and even external partners. Failure to achieve this buy-in often resulted in lack of resources and internal support.

► **The specific case of funded projects:** EU or national funded projects, on the other side, often lacked sustained scaling strategies post pilot and failed to transition into widespread adoption among the broader base of micro and small enterprises.



07

The intrinsic value of Blockchain exploitable in the global agri-food sector

7.1. Main areas where BCT acquires value

Blockchain technology (BCT) is versatile and serves both as a **data infrastructure** and as a **foundation for financial applications**, but the focus depends heavily on the sector and use case.

In sectors like agrifood, healthcare, logistics, and supply chain management, blockchain primarily functions as a secure, tamper-proof ledger to record and share data transparently among multiple parties. Here, the emphasis is on:

- **Data integrity and immutability:** ensuring records can't be altered without detection.
- **Traceability and transparency:** who submitted what, and when
- **Auditability:** supporting investigations and recalls
- **Accountability:** when combined with legally-binding digital identity frameworks like EUDI (European Digital Identity Wallet), blockchain becomes an accountability infrastructure.

In these contexts, blockchain does not require any cryptocurrency or token. It acts like a shared database that is verifiable, accountable and auditable.

This does not completely exclude the possibility to use blockchain to enable new financial services. In fact, as we will see later on, there are financial applications for the agriculture sector such as <https://agridex.com/> that allow to buy and pay for agricultural commodities in stablecoins (a type of cryptocurrency) for less intermediary cost and much faster settlement time compared to traditional financial service providers.

Analysing applicative use cases and discussing with Stakeholders in Working Groups, it emerged that not all players are inclined to make their operations more transparent or to share data, **especially when this is not mandatory**.

Instead, we noticed that blockchain technology acquired value for those supply chain players with a particular **sensitivity for broader societal aspects**.

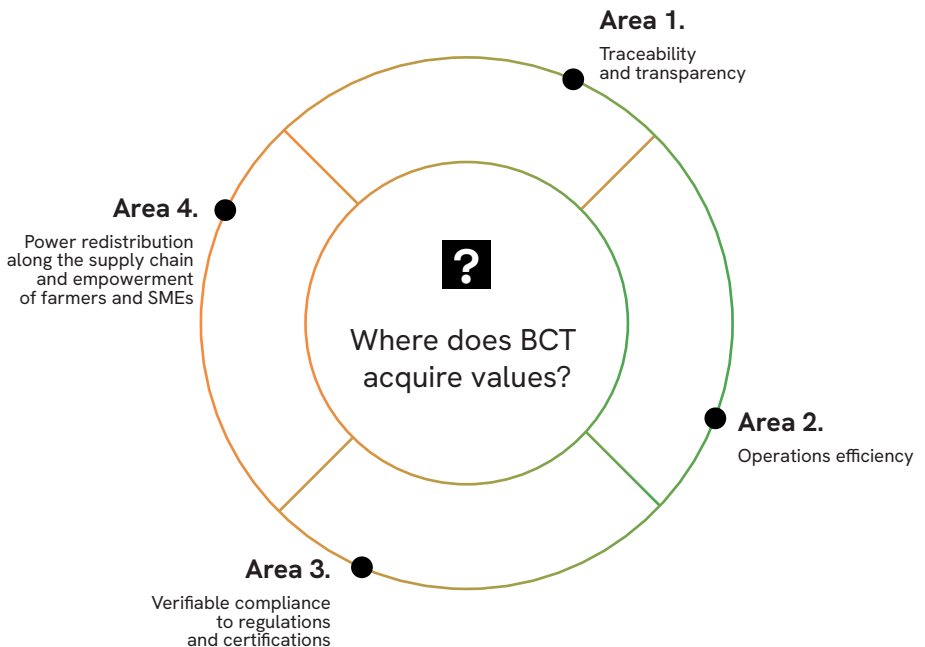
In absence of immediate evidence on ROI, most of the use cases currently in production phase moved their attention to other values. Successful projects are those that articulate clear objectives aligned with business benefits (operational efficiency) but also with public good outcomes (e.g. consumer trust, public health, social inclusion) and environmental benefits (sustainability).

TRUSTyFOOD consortium identified **four main areas where BCT acquires value**:

- **Area 1. Traceability and transparency**
- **Area 2. Operations efficiency**
- **Area 3. Verifiable compliance to regulations and certifications**
- **Area 4. Power redistribution along the supply chain and empowerment of farmers and SMEs**

Some areas have already paths that can be pursued, others have paths desirable but not entirely proven. For each of these, this section reports the implicit value behind it, the problem identified, the consequences, and the role that blockchain can play in making the food system more resilient, safe, and sustainable in the medium to long term.

The analysis reports also if some concrete success stories exist or if the benefits remain still at a theoretical level and require additional investments (e.g. in R&I).



Area 1 – Traceability and transparency

The value

Ensure public health; consumer trust.

The problem

The EU's General Food Law entered into force in 2002 and made traceability compulsory for all food and feed businesses. It requires that all food and feed operators implement own traceability systems. They must be able to identify where their products have come from and where they are going and to rapidly provide this information to the competent authorities. Business operators have to document the names and addresses of the supplier and customer in each case, as well as the nature of the product and date of delivery. The current traceability practices stop at "one step back, one step forward"¹¹, not really guaranteeing what is commonly defined end-to-end traceability (from field to shelf, including intermediaries, not just suppliers). The traditional agrifood supply chain remains opaque and fragmented, making it difficult to trace a product's journey from farm to fork. This lack of visibility is a major issue, especially in complex global supply chains.

The consequences

1. Food safety incidents: When contamination or recalls occur, identifying the source quickly and precisely is challenging, leading to wider recalls, increased waste, and prolonged health risks. Europe experiences dozens of food-safety recalls each week, with recurring chemical (pesticide residues, heavy metals, disinfectant by-products) and microbiological risks (Salmonella, Listeria, hepatitis A). While the overall number of recalls might not always indicate a decline in food safety, the severity of foodborne illnesses associated with recalled products has increased in some instances. Certain sectors—like fresh produce, nuts/seeds, herbs and cheeses—are consistently exposed to both chemical and biological risks depending on origin, handling, and regulation compliance.

2. Inefficient recall management: Recalls become long (can require days or weeks), broad and costly¹² because it's difficult to isolate affected batches.

3. Limited accountability: It's hard to pinpoint responsibility when issues arise, making it difficult to hold specific actors accountable for quality or safety failures.

4. Food fraud and counterfeiting: Products are susceptible to mislabeling, adulteration, or outright fraud (e.g., misrepresenting origin, organic claims, or specific certifications), eroding consumer trust and harming legitimate producers.

¹¹ https://food.ec.europa.eu/system/files/2016-10/gfl_req_factsheet_traceability_2007_en.pdf

¹² A recall costs a company on average between 8 and 10 million Euros between organizational and logistical costs for the recall of goods and lost sales, bad corporate image and time and resources allocated to investigate the causes of the problem, the temporary shutdown of the production line until all critical issues are solved and the disposing of contaminated products.

Who is impacted

Consumers, producers, governments/control authorities

What blockchain can do

The blockchain in agriculture and agri-food supply chain is positioned as the technology backbone of next-gen food integrity solutions. Let's see in more detail what we mean:

► Enhanced inter-sectoral traceability

When properly applied in an end-to-end perspective, i.e. securing and sharing data captured making large use of IoT devices at different points throughout the entire supply chain, often across multiple, independent entities (not limiting thus to "one step back, one step forward"), making each actor's claims and inputs auditable and traceable, every step – planting, harvesting, breeding, processing, packaging, transportation, storage, and sale – could be potentially* recorded, providing an unalterable history visible to all authorized parties across the supply chain, including producers, processors, distributors, retailers, and even regulatory bodies. It helps mapping the responsibility chain.

Through QR codes on the package, the consumer can scan and obtain in real-time product's information. *[We used the term "potentially recorded" as at this stage, not regulated, it is up to the producer the decision on what data can be saved in blockchain and what should remain off-chain]. At global level⁷, around 50% of the market's focus is on enhancing end-to-end traceability. Most of the use cases analysed – in particular in charge of food industrial partners and their supply chain starting from farmers – fall into this category. We mention only few case studies:

CHO and IBM: Enhancing Olive Oil Traceability – Terra Delyssa extra virgin olive oil.

The system tracks the product over eight quality assurance checkpoints, including the farm where the olives were produced, the factory where they were processed, and the departments where the oil was drained, bottled, and distributed (end to end traceability - orchard, mill, filter, bottling, etc.). This initiative aims to provide a verifiable record of the product's journey. The system is not experimental or limited to test batches — it's integrated into CHO's every production run of its Terra Delyssa extra virgin line. It's definitely beyond the pilot phase — it has been a live, large-scale, consumer-facing production system since about early 2020.

Barilla and pesto alla genovese – vegetable - complete digitalization of the supply chain of fresh basil used for pesto alla genovese, where the blockchain certifies the permanent and unalterable record of every step. The system involves 50 operating units, 19 agricultural companies and six suppliers, in addition to the processing plant in the province of Parma. Started in 2023, the project is no longer limited to a pilot phase: it is currently defined as fully operational and on an industrial scale.

Blockchain could also enable customs authorities to obtain the required information for customs declarations. Abu Dhabi, Korea and Hong Kong Customs are already experimenting blockchain for this purpose. In Egypt, CargoX is integrated into the national NAFEZA single window platform as the authorized blockchain document transfer gateway for Advance Cargo Information (ACI). It enables secure, immutable, and electronic submission of trade documents—streamlining customs clearance. As a result, cargo release times have dropped from around 29 days to between 3 and 9 days, compliance costs have fallen significantly, and overall efficiency has markedly improved.

At European level, we mention **EBSI project “e-Origin”** - Helping customs brokers, online sellers and marketplaces to resolve customs compliance issues and IOSS (Import-One-Stop-Shop) fraud in cross-border e-commerce. The pilot involves VAT administration, marketplaces, online sellers, customs brokers and customs authorities in Europe¹³.

► **Improved food safety and quality in complex supply chains/ Reduced waste**

In the event of a foodborne illness outbreak or recall, blockchain’s immutable records allow for rapid identification of the source, limiting the scope of the recall, reducing food waste, minimizing public health risks and economic losses and protecting consumers more effectively. Food crises (e.g. the 2018 E. coli outbreak linked to romaine lettuce) highlighted the limitations of traditional traceability systems, but blockchain was not implemented during that incident. However, controlled tests and proofs-of-concept (e.g. Walmart, with products like Chinese pork and US mangoes) have been conducted to demonstrate how data saved on blockchain could noticeably reduce the time needed to trace the origin of food to few seconds.

► **Increased transparency across the value chain**

All stakeholders in the agrifood value chain, not just consumers, can potentially gain unprecedented access to verified information about product origins, production methods, certifications (e.g., organic, fair trade), and even environmental impact. This shared, verifiable data can foster collaboration among different actors (farmers, processors, logistics providers, retailers), leading to more efficient partnerships and better decision-making throughout the entire chain. In this field are included mainly R&I projects which act as proof-of-concept (here are some examples: TRICK Project, WATSON, TITAN, Axfoundation’s Blockchain Initiative in Sweden, Signeblock in Spain, BBTWINS EU project: <https://bbtwins.eu/about-bbtwins/>)

► **Proof of origin/authenticity and fraud deterrent**

Provided it’s implemented with robust data input controls, blockchain can serve as proof of authenticity and can protect EU-branded food products (e.g., Parmigiano-Reggiano, Mozzarella di Bufala Campana DOP, Grana padano DOP, Champagne, Port Wine and Madeira Wine) from counterfeiting. An example is reported by Vigneti Massa in Italy which

¹³ <https://ec.europa.eu/digital-building-blocks/sites/display/EBSI/e-Origin>

has implemented a “smart cap” technology that features blockchain and IoT. Each bottle of the production is equipped with a unique RFID chip that is integrated on the capsule. Once scanned with the smartphone NFC reader, the consumer is able to view the blockchain-registered information that related to that particular wine.

Also, blockchain can provide evidence to global supply chain (e.g. *Lavazza, Reserva de ¡Tierra! Cuba blend* - coffee tracks the coffee’s journey from the farm to the cup using blockchain technology, making transparent the coffee’s origin and processing).

At research level it is noteworthy a research project - *CheeseChain* - from Switzerland which ensures authenticity of Tete de Moine cheese through DNA sampling. By storing biological data, specifically DNA information, on a blockchain, the project aims to create an immutable and tamper-proof record of the cheese’s origin and production process. This combination of blockchain and DNA authentication helps to verify the authenticity of the cheese and provides consumers with greater confidence in the product’s origin and quality.

LET’S MAKE THINGS CLEAR

Q. Is traceability possible also without blockchain?

A. Yes. Many businesses from EU or non-EU countries (e.g. Egypt) achieve effective, reliable traceability without blockchain. Traditional systems—using supply chain software—collect data from all stages (raw materials, processing, logistics, retail) into centralized databases. These platforms often integrate live updates via IoT devices, RFID tags, QR codes, barcodes, and manual inputs. They support real-time visibility, enable recalls, ensure regulatory compliance, enhance quality control, and provide transparency that builds consumer trust.

Popular platforms include SAP SCM, widely adopted in the agrifood sector for dairy, protein, farm, and supply chain management, and Oracle SCM Cloud/NetSuite, used by agtech firms. These generic platforms are often tailored to industry-specific needs. Some solutions are purpose-built, like AgriChain, a centralized, cloud-based platform used by growers, processors, and buyers across Australia and Asia, and SourceTrace, deployed in 37 countries, which offers real-time data collection from farms to retail for complete agricultural value chain management. Other tools include TruTrace, Retraced, and BanQu.

Q. Is non blockchain traceability efficient and scalable?

A. Yes, when properly implemented. Automation through IoT and RFID reduces errors and improves data accuracy. Centralized platforms can scale across large supplier networks, even globally, supporting compliance and sustainability efforts.

Q. Can non blockchain traceability systems guarantee quick recalls?

A. Yes, if digital and well-structured. Modern systems with real-time data capture, batch-level traceability, and automated notifications enable quick and targeted recalls. Structured data formats (like KDEs) and clear tracking points (CTEs) help companies isolate affected lots, inform partners, and take corrective action swiftly.

However, speed and reliability depend on avoiding data fragmentation, inconsistent formatting, manual records, or interoperability gaps—issues that slow down traceback and hinder compliance.

Q. What unique value does blockchain add?

A. The following is clarified:

1. Traditional IT systems rely on a single authority to manage the data, meaning transparency and data integrity depend on that organization's governance and controls.

2. Through BCT, non-repudiation of legally-binding statements can be achieved easier than with legacy systems.

3. Tamper-proof records: blockchain ensures that once data is entered, it can't be altered without detection. This level of integrity surpasses traditional systems, which depend on internal controls.

4. Accountability: especially when paired with legal identities and enforcement frameworks, it enables accountability.

5. Shared ledger across stakeholders: instead of siloed databases reconciled manually, blockchain provides a verifiable, immutable ledger accessible to all authorized participants. While centralized systems can mimic this, they lack the same audit resilience and distributed trust model.

6. Smart Contract automation: blockchain enables rule-based automation—like auto-triggering payments upon verified delivery or issuing digital certificates when sustainability criteria are met. This reduces paperwork, speeds up processes, and lowers compliance burdens.

Area 2 – Operations efficiency

The value

Efficiency (ability to perform a task or achieve a goal by using available resources in the most optimal way, minimizing waste and maximizing results)

The problem

Agrifood companies often struggle with inefficiencies in managing internal and supply chain operations. Core business processes—such as procurement, inventory management, quality control, and logistics—are frequently fragmented, poorly integrated, and reliant on outdated or manual systems. The lack of streamlined data management within the organization or data validation operations in a trustless chain (which require time and resources) hinders operational effectiveness, slows decision-making, and creates bottlenecks in daily activities.

The consequences

1. **Redundant workflows** and inefficient resource allocation
2. **Delayed internal processes:** Inadequate coordination across departments leads to slow approval cycles, missed production or shipping deadlines, and longer response times.
3. **Higher risk of human error:** The absence of automated data verification and integration increases the likelihood of mistakes in inventory records, order processing, and compliance documentation.
4. **Lack of real-time visibility:** Without centralized and up-to-date information, managers face difficulties in tracking product status, forecasting demand, or responding quickly to disruptions. (*As we will see in the dedicated Area 3, this can impact also certifications and audits)
5. **Ineffective decision-making:** Data silos and inconsistent reporting reduce the company's ability to analyze performance accurately and adapt to market or operational changes.

Who is impacted

Producers

What blockchain can do

► **Optimization of the supply chain: reduction of costs, times and errors thanks to more efficient management of information, financial flow and processes / reduced waste** By providing a shared view of inventory, logistics, and transactional data, blockchain can lead to greater operational efficiency within individual companies.

Most of SMEs who applied blockchain with an initial different purpose (e.g. increasing consumer trust), expressed their satisfaction in terms of improvement in internal efficiency as an indirect consequence, even if it was not immediately quantifiable in terms of savings.

For the same reasons, blockchain can streamline operations across different companies in the supply chain, reducing administrative burdens and optimizing routes. This aspect was widely discussed in the academic literature but there were just few documented real use cases where the solution was designed for these purposes, **which emerged rather as an immediate consequence**. Such benefit comes more often in long and complex supply chains, which involve different actors and an important volume of information. Retailers (being at the end of the supply chain) are often involved. As an example, we mention the experience of Migros (Switzerland) who declared to have implemented TE-FOOD's blockchain solution to fresh produce supply chain not just for transparency, but to reduce operational costs, minimize human errors, accelerate product recall processes, optimize inventory handling and reduce food waste.

► **Reduced supply chain inefficiencies automating processes through smart contracts**

↳ **USE CASE:**

(BLOCKFIL – F/200070/01-03/X45) at GIAS srl in Italy

Preamble: In many companies, it typically takes 30 to 90 days to receive payment after completing a delivery or task. Processes are often manual—generating and emailing invoices, followed by slow data entry and processing.

The test done: A shipment of frozen vegetables was recorded on a blockchain. Each batch included IoT sensors (GPS, temperature, humidity) to protect the cold chain. The shipment was destined for a designated point of sale. The IoT-equipped container tracked and transmitted real-time data on location and temperature to a blockchain-based cloud service. Smart contracts specified transport conditions, such as: “If the temperature exceeds -Y°C, the store may reject the shipment.” Any breach made the supplier liable. This data was stored on a transparent blockchain ledger, allowing traceability of the shipment's journey and verification of cold chain integrity. If contractual terms weren't met—e.g., late delivery or incorrect destination—the product could be automatically excluded from acceptance and payment, using a smart contract and escrow mechanism.

Advantages: Blockchain enables real-time payment through smart contract. Once conditions are verified (e.g., delivery and temperature compliance), invoicing and payment are automatically triggered—via tokens or traditional banking. This streamlines the supply chain and reduces working capital needs.

Area 3 – Verifiable compliance to regulations and certifications

The value

Consumer trust; Sustainability; to unlock access to richer and regulated markets for the long tail of small producers

The problem(s)

In the agrifood sector, new regulations are frequently introduced, often with the goal of improving food safety, environmental protection, animal welfare, or sustainability. While these regulations are necessary and beneficial in the long term, they can create significant challenges especially for farmers and SMEs who do not have the knowledge and the tools to adapt quickly, suffering from an overload of new practices, paper and burden (e.g. EU-Deforestation Regulation (EUDR), which will be applied from December 30, 2025 or FDA Food Traceability Rule, mandatory by 2028).

With reference to **certifications** (e.g. “organic,” “sustainable,” “carbon neutral”), have lost credibility in many areas due to vague standards, weak enforcement, and greenwashing^{14, 15}. For many producers, certification has become a checkbox exercise to access markets—particularly for exports to the EU—rather than a genuine commitment to best practices. Consumers and NGOs increasingly criticize both public and private schemes for lacking transparency and meaningful impact. The sector suffers from a proliferation of overlapping standards (e.g. Organic, Rainforest Alliance, GlobalG.A.P., LEAF, Fairtrade), creating confusion and fragmentation. Without harmonisation, it is difficult to assess which labels truly reflect sustainable practices.

Moreover, most certification processes still rely on paper-based or siloed digital systems, leaving them vulnerable to manipulation and lacking real-time, end-to-end supply chain visibility. This makes it harder for certifiers to ensure that all practices across production and handling meet required standards—raising the risk of non-compliance or revocation.

Another issue refers to **inefficient auditing processes**¹⁶. Audits are frequently manual, time-consuming, and expensive, often relying on records that can be easily falsified. Data silos between producers, processors, certifiers, and regulators further hinder the accuracy

14 Paweł Nowicki, Marek Ćwiklicki, Piotr Kafel, Magdalena Wojnarowska, Credibility of certified environmental management systems: Results from focus group interviews, *Environmental Impact Assessment Review*, Volume 88, 2021, 106556, ISSN 0195-9255, <https://doi.org/10.1016/j.eiar.2021.106556>.

15 Marschlich, Sarah & Hurtado, Ellis. (2025). The effect of third-party certifications on corporate social responsibility communication authenticity and credibility. *Corporate Communications: An International Journal*. 30. 1-20. 10.1108/CCIJ-01-2024-0015.

16 Chang, H., Kao, Y.-C., Mashruwala, R., & Sorensen, S. M. (2017). Technical Inefficiency, Allocative Inefficiency, and Audit Pricing. *Journal of Accounting, Auditing & Finance*, 33(4), 580-600. <https://doi.org/10.1177/0148558X17696760> (Original work published 2018).

and consistency of assessments. Inspectors commonly base their evaluations on spreadsheets, invoices, and handwritten logs, which are difficult to verify and standardize. As a result, audits are not only prone to error but are also often duplicated by different certification bodies, leading to redundant work, increased costs, and audit fatigue for producers.

The consequences

The above-mentioned systemic weaknesses limit the ability of producers—especially smallholders and SMEs—to compete fairly in global markets, risking non-compliance, loss of certifications, or exclusion from premium markets.

Who is impacted

Producers—especially smallholders and SMEs; consumers (in terms of confidence); regulators, certifiers/auditors

What blockchain can do

► Prove compliance with regulations and certifications

By systematically recording and sharing key data about their practices, inputs, and products, farmers and SMEs could demonstrate compliance with regulations and certifications. Traditionally, this has been done through paper records and inspections, but **digital tools¹⁷, especially blockchain, could significantly enhance the reliability, traceability, and verifiability of this information.** Regulators and auditors can instantly access historical data access real-time, tamper-proof data for inspections. This reduces frauds and delays in compliance checks and makes audits more efficient and accurate. Automating compliance checks using smart contracts is also possible.

↘ USE CASE

As of now (August 2025), there is no single, universally recognized regulation—in the U.S., EU, or globally—that explicitly requires or certifies blockchain as the official method to prove compliance with food safety regulations (such as the FDA's Food Traceability Rule or EU traceability laws), thus there is no deployed running example of this happening yet. However, blockchain can be used to support compliance, and regulators are increasingly open to it as a voluntary or supportive tool, not a mandated one yet.

► Blockchain as a tool to demonstrate ethical and sustainable practices

Sustainability is one of the key drivers of technological innovation in agriculture, as both consumers and regulatory bodies demand more responsible practices (EU Green Deal). Blockchain has significant potential to improve sustainability by providing transparent records of agricultural practices, from input usage (e.g., fertilizers, pesticides) to water consumption and carbon footprint. For example, blockchain could be used to monitor

¹⁷ <https://a.altodoc.aalto.fi/items/246e006b-f51e-464a-adf0-f579a7df68e1>

sustainable farming practices, allowing both regulators and consumers to verify whether farms are adhering to environmental standards. Additionally, it can help in tracking and trading carbon credits or other sustainability-linked initiatives, providing farmers with the opportunity to monetize their environmentally friendly practices.

Key Benefits:

1. Real-Time environmental monitoring and verified sustainability tracking: Blockchain can integrate with IoT sensors on farms to collect real-time data on water use, greenhouse gas emissions (e.g. CO₂, CH₄, N₂O), pesticide levels, and other environmental parameters. Logging this data on a tamper-proof blockchain ledger creates verifiable records that demonstrate compliance with environmental standards, enable accurate carbon footprint assessments, and support sustainability certifications. This enhances transparency across the supply chain and regulatory processes and helps producers and retailers make data-driven decisions to reduce emissions and resource use.

2. Incentivising sustainable practices through tokenisation: Blockchain can support digital reward mechanisms such as tokens or credits for farmers who implement sustainable practices (e.g. water-saving irrigation, reduced fertiliser use). These tokens can be traded, linked to subsidies, or used in carbon markets, creating financial incentives that accelerate the green transition in agriculture.

Approximately 20% of the market's new growth is coming from these emerging use cases that combine financial incentives with verified sustainable practices. This expansion shows the market's huge potential to reshape how farms operate and profit sustainability.

» CONCRETE CASES:

OpenSC: WWF's blockchain platform for sustainable seafood

OpenSC, a platform developed by WWF Australia and BCG Digital Ventures, uses blockchain to enhance the transparency of global supply chains, starting with fish caught in sub-Antarctic waters. The platform captures **data at every point in the supply chain to verify claims of sustainable production**. Consumers can access this information by scanning QR codes on products, promoting informed decisions and ensuring that the food consumed does not contribute to environmental degradation or social injustices.

Area 4 – Power redistribution along the supply chain and empowerment of farmers and SMEs

The value

Social inclusion (have access to credit, to open new markets opportunities which currently are denied).

The problem

Traditional supply chains are centralized, with a few corporations dominating pricing, logistics, and standards.

The consequences

Farmers and SMEs cannot participate in decision-making about pricing rules, undergoing the decisions of others. In most of the cases there are intermediaries in trading processes.

Who is impacted

Farmers—especially smallholders

What blockchain can do

► **Empowerment of farmers, fairer practices and access to new markets**

Key Benefits:

1. Through the disintermediation, blockchain can provide farmers with more direct access to markets (connecting directly with retailers, consumers, or exporters), reducing their reliance on intermediaries. It can ensure fairer pricing and transparent payment terms. Nearly 25% of major producers are piloting blockchain-based smart contracts for automating fair payments and reducing payment delays to farmers.
2. Farmers and SMEs can build digital reputations based on verifiable data stored on the blockchain (e.g., compliance history, delivery records, sustainability metrics). This can open up access to credit/ microfinancing and certifications. About 15% of start-ups are designing blockchain systems that link regenerative farming practices to carbon credit trading, helping farmers earn 10-20% more.
3. Blockchain can create a fair marketplace that benefits every participant, from the smallest farmer to the largest distributor.

▶ CASE STUDY

AgriDex

AgriDex leverages Solana's scalability and low fees, combining stablecoin-based payments (like USDC) and smart contracts to give farmers—including smallholders with internet access—direct access to international markets, with no need for technical expertise. The platform tokenizes agricultural goods and farmland into digital assets, enabling direct interaction between farmers, cooperatives, traders, and investors. Smart contracts handle onboarding, payments, invoicing, and transfers of ownership, all recorded immutably on-chain.

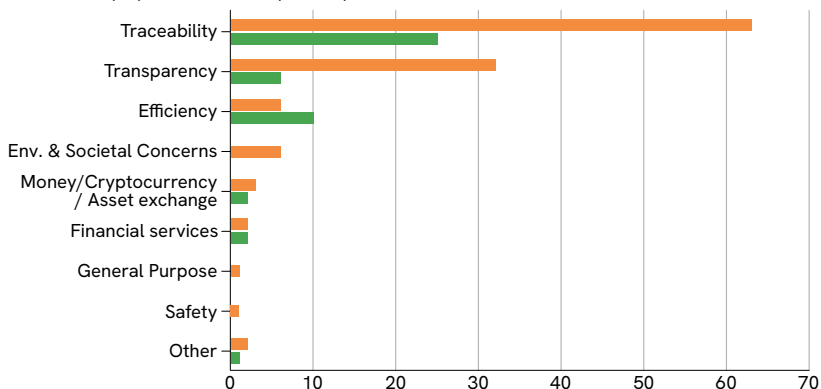
In July 2024, AgriDex completed its first live trade: wine and olive oil shipped from South Africa to London. Fees were just 0.15% per party, and settlement was nearly instant compared to traditional systems, which can take days. This approach improves cash flow, reduces reliance on trade finance and currency services and redistributes value more fairly across the agrifood sector.

Another example is **Farmsent**. Through Farmsent's platform, farmers gain unprecedented ownership of their produce, selling directly to consumers without the interference of intermediaries, reducing prices for consumers while increasing profits for farmers.

In terms of current applications, our analyses of 320 use cases (the figure below) demonstrated that **traceability represents the main reason for blockchain application in agrifood to date**. This is perfectly in line with global market data⁶ which reports as traceability demand boosts market growth worldwide. Follow transparency and efficiency and case studies pertaining to topics including carbon footprint, decarbonisation, and carbon credits tokenisation. The financial part is currently a minor component.

GLOBAL USE CASES MAIN GOAL

■ Main Goal (EU) ■ Main Goal (Non-EU)



7.1.1. Enabling conditions for success stories

- **Reliable internet access.** Clear identification of what specific issue the technology addresses
- **Use verified data sources and trusted oracles, traceable and non-repudiable:** blockchain alone is not enough, since it lacks the ability to directly interact with the physical world—which is where IoT devices operate. “Data bridges” are necessary to bring data from the “real world” on the blockchain
- **Inclusive Ecosystems:** all stakeholders involved—this includes management, IT departments, business units, and even external partners
- **Trusted governance models:** clearly define who enters data, who has permission to view or edit, who triggers smart contracts, dispute resolution, data ownership, and privacy concerns—especially important in food systems with competing interests.

7.1.2. Who can benefit more from blockchain

Blockchain is not a one-size-fits-all solution, applicable horizontally to each firm.

Who might NOT benefit (much) from blockchain for traceability purposes.

- **Firms looking only for data storage**
Blockchain is not primarily a data storage system, it’s not meant for storing large files or arbitrary data or huge databases. Due to its decentralized nature, storing large amounts of data on-chain would be expensive and inefficient. Instead, blockchain often stores hashes or references (pointers) to off-chain data stored elsewhere (e.g., IPFS, traditional databases). For farmers or smallholders, traditional databases are cheaper and faster unless multiple parties need to verify/validate data.
- **Who searches only for intra-company efficiency,** normal digitisation for intra-company operations suffices.
- **Small, local producers with short supply chains,** target: small farms, SMEs:

BLOCKCHAIN FEATURE	NEED	REASON
Decentralized trust	No	In a short, local supply chain, trust is often personal or community-based. Blockchain adds unnecessary complexity.
Immutable, shared ledgers	Not needed	Few actors involved
Assists tracking & provenance	Overkill	Few actors involved. Simpler systems are enough
Scalable data interoperability	Irrelevant	Few actors involved
Used to standardize data across fragmented systems	Irrelevant	Limited data integration needs
High setup/maintenance cost	Burdensome	For small businesses with limited budgets this can represent a significant burden

Ideal Use Cases

- Based on **end-to-end traceability in global trustless supply chains** (long and complex, with little transparency). Global agri-food supply chains are characterized by:
 - ▶ Numerous intermediaries: farmers, aggregators, exporters, shippers, processors, wholesalers, retailers
 - ▶ Geographical dispersion: actors operating across different legal and regulatory environments
 - ▶ Information silos: data stored in disconnected, proprietary systems
 - ▶ Low visibility and traceability: difficult to verify product claims or respond to disruptions

In such a context, blockchain can serve as a foundational infrastructure for transparency, and accountability across the entire agrifood chain.

Type of products to prioritize:

- ▶ **High-value products.** Indeed, these products rely heavily on credibility of claims (e.g., organic, fair trade, protected origin), through BCT verifiable digital trails improve consumer trust and enable premium pricing. High-value products—like extra virgin olive oil, premium pasta, wine, special beef, cured meats, or cheese—often justify their higher price through credence attributes such as claims of **origin (PDO/PGI), artisanal production, and tradition**. Blockchain allows these claims to be transparent, digitally certified and tamper-proof, justifies premium price and positioning, builds consumer trust.

- ▶ Products like **coffee, cocoa, seafood, and palm oil** often travel through multiple intermediaries. This complexity introduces challenges in tracking product origin, ensuring quality, avoiding frauds, verifying certifications, and responding to food safety incidents. In this context, blockchain provides a decentralized, tamper-resistant system for tracking every transaction and movement along the cross-border supply chain.

→ CAN BE ALREADY IMPLEMENTED

- **Certifications & audits:** Certification Bodies and Government Regulators need reliable, tamper-proof systems for food safety, compliance, and recalls. Blockchain allows real-time auditing and reduces fraud in certification processes (e.g., organic, Halal).

Possible examples

- ▶ **Organic Certification:** Blockchain can record each step in an organic supply chain—input use, farm practices, storage, transportation, and processing—verifying organic integrity and reducing greenwashing.
- ▶ **Halal Certification:** From animal handling to slaughter and processing, each step can be verified by accredited bodies and uploaded to a blockchain ledger, ensuring compliance with religious standards across geographies.
- ▶ **Food Safety Inspections:** Results from lab tests and facility inspections can be uploaded by authorities and automatically linked to products or shipments, ensuring swift recalls and accountability.

30%

smart
contract
adoption
increase

► *Protected Geographical Indications (PGIs)*: Blockchain can record origin, harvest details, and producer information to protect EU-branded food products (e.g., Parmigiano-Reggiano, Champagne, Port wine) from counterfeiting.

- **Assist businesses to demonstrate environmental credence claims.** Blockchain technology enables businesses to transparently and securely validate their environmental credibility claims by providing immutable records of sustainability practices and supply chain data.

→ **Implementable at present on a voluntary basis, not a mandatory one.**

- **Supply chain finance:** E.g., enabling credit based on verified delivery or harvest.

→ **ADVISABLE but little implemented to date**

Conclusions

BCT main use has been so far related to 'enhance traceability'. For individual firms or short supply chains, traditional databases and data management technologies may be more appropriate, cheaper, and easier to implement. BCT is evidently best used where data immutability, transparency, and decentralization are essential. In such context, the possibility to exploit the BCT potential during food recalls remains a big opportunity, but it has been tested only under controlled conditions so far.

Its use to discover/prevent counterfeiting has been tested at pilot-level (e.g. research projects) but data on its efficacy in real operativity requires time.

The possibility to exploit its potential in certifications and audits remains a big

opportunity but few explored. The same for supply chain finance: blockchain can tokenize agricultural goods and farmland into tradeable digital assets, providing new markets access and benefits for farmers and SMEs, but few cases are currently reported and all out of Europe.

Application of blockchain for 'increasing efficiency' is mainly a consequence related to its use for traceability purposes, rather than the main reason for its direct application. However, including smart contracts in this specific case, we noticed that the 'adoption of smart contracts' is rapidly increasing, representing 30% of the market growth worldwide⁶. In the use cases, we observed that smart contracts have been tested in their proof-of-concept, without moving at a full-implementation.

Indeed, such type of contract agreements are not regulated making hard for producers every-day life adoption. An intervention at policy level for making them enforceable is necessary to fully exploit the opportunities offered by blockchain technology in automating and simplifying processes.

However, we emphasize the fact that any process rule that is coded in a smart contract but ingests events happening outside of the BC system itself (typically, in the real-world) must guarantee as much as possible the trustworthiness of the sources of information they rely on to make sense and reliability to the overall process.

7.1.3. False myths to debunk

1. Myth: Blockchain consumes too much energy to be viable in the agrifood sector

This is a common misconception rooted in the energy-intensive nature of proof-of-work (PoW) blockchains like Bitcoin. However, most blockchain solutions relevant to the agrifood sector do not use PoW. Instead, they rely on energy-efficient consensus mechanisms such as proof-of-stake (PoS), proof of Authority (PoA), or permissioned blockchains, which consume minimal energy compared to public ledgers. Many agrifood applications involve private or consortium blockchains, where participants are known, significantly reducing the computational overhead and governance risks. Furthermore, when blockchain is part of a broader digital system—including IoT and AI—its energy footprint is often offset by gains in efficiency, reduced waste, and streamlined processes.

Therefore, concerns about energy use should not be a deterrent, especially when implemented responsibly with the right architecture.

2. Myth: Blockchain is just hype with no real value

While blockchain has indeed been subject to hype—particularly during speculative booms—this perception ignores the practical, growing applications in agri-food sector. Blockchain has been successfully tested to improve traceability, combat food fraud, verify sustainability claims, and streamline certification processes (e.g., for organic, PDO, or PGI products). Unlike hype-driven speculation such as ICOs, these use cases focus on data integrity and transparency, which are core challenges in complex food supply chains. Moreover, blockchain is increasingly being integrated with other technologies like IoT and AI, delivering real-world impact in

areas such as food safety, logistics, and climate-smart farming. Dismissing blockchain as mere hype risks overlooking valuable innovations already underway.

3. Myth: Blockchain eliminates the need for trust

Blockchain diminishes reliance on centralized authorities, though elements of trust remain necessary within the system. Users still need to trust the quality of data inputs, the design of the smart contracts (which depending on external data cannot be more reliable than the sources feeding it), and the governance of the blockchain network. Trust is minimized and shifted—not removed—requiring new forms of collaboration and accountability. The latter is an important point: traditional blockchain rhetoric often emphasizes “trustlessness”—i.e., you don’t need to trust a central party because the system is decentralized and self-verifying.

But in real-world applications (e.g., supply chains, public registries, digital governance), what’s more critical than eliminating trust is ensuring accountability: Who did what, when, and under which digital identity? When combined with legally-binding digital identity frameworks like EUDI (European Digital Identity Wallet), blockchain can: Record actions immutably, Link them to verified legal identities, Serve as evidence in audits or legal proceedings.

Hence, blockchain becomes an accountability infrastructure, not just a decentralization tool.

4. Myth: Blockchain offers real decentralisation

Blockchain enables decentralisation, it is technically possible. However, the way it is being implemented in the agrifood sector today is typically through permissioned or consortium blockchains, where a limited

number of known, pre-approved actors (e.g. supply chain companies, certifiers, regulators) control the network.

This means that instead of a fully open and decentralized system, we often see semi-centralized architectures with shared control among trusted stakeholders.

This “managed decentralisation” offers benefits—such as improved efficiency, better data governance, and faster consensus—but it also means that the original vision of decentralisation (as seen in cryptocurrencies like Bitcoin) is not fully realized. In fact, real decentralisation in agrifood would require broader participation by smallholder farmers, cooperatives, and even consumers—something that is still rare due to barriers like digital illiteracy, connectivity issues, and lack of incentives.

Moreover, decentralisation in agrifood is complicated by power imbalances. Larger actors (e.g. multinational food processors or certifiers) often have more control over data entry, system design, and governance rules—potentially recreating the centralized structures blockchain was meant to disrupt.

5. Myth: Integration of blockchain with other IoT/cloud/AI systems would automatically guarantee trustworthiness/integrity of systems

While integrating blockchain with IoT, cloud, or AI systems can enhance trust, it does not automatically guarantee the trustworthiness or integrity of the entire system. Apart from the GIGO problem, we need to consider that most IoT devices are resource-constrained and often lack robust security features. Even with blockchain, a compromised device can inject false data into the network. Cloud platforms still require access control, identity management, and data governance. If the cloud system interacting with the blockchain is

misconfigured or compromised (e.g., open database or leaked API key), the blockchain integration won’t protect against those weaknesses. AI can amplify bias or errors. Yet integration is different from interoperability or Validation: just connecting these systems together doesn’t mean they validate or audit each other.

6. Myth: When a QR-Code is displayed on a product, it must be a link to blockchain-based information

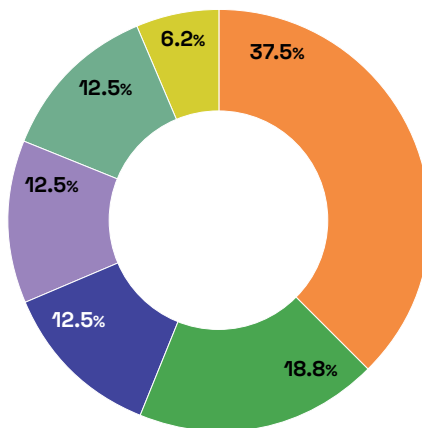
This statement is misleading. While QR codes linked to blockchain can provide transparent and tamper-proof information about a product’s origin, journey, and certifications, they are not the only way for consumers to access such information.

Producers can link product info (e.g., origin, practices, dates) to a simple QR code connected to a cloud service or website. Other technologies and systems—like centralized databases, NFC tags, product websites, or supply chain platforms—can also deliver detailed product traceability and history. What changes is the level of accountability associated to such tool.

7.1.4. Challenges to implementation: sum up

The analysis of the failures on one side and the analysis of the agri-food eco-system on the other underlined that different factors slow down or prevent blockchain from being fully exploited in this sector. Let's look at the various points, in order of priority based on what emerged in the Working Groups and start introducing the preliminary co-created strategies to be implemented for solving them.

MAIN HINDERING FACTORS IN DELIVERING BCT



■ End user awareness
 ■ Technical skills
■ Maturity of technologies
 ■ Innovation risk
■ Regulatory compliance
 ■ Data interoperability

1. Unbalanced level of digital maturity

We approached the problem at food system level, in a farm-to-fork perspective. In many agricultural regions—particularly rural or underdeveloped areas—digital infrastructure and readiness remain limited. Without adequate internet access, modern devices, and support systems, farmers and small producers risk being excluded from blockchain-based ecosystems.

Addressing this requires investment in digital infrastructure, connectivity, and local support services to ensure inclusive participation and equitable access to blockchain benefits to all the actors of the agri-food system, indiscriminately.

2. Lack of awareness, digital literacy and skills

A major barrier to blockchain adoption turned out to be the lack of awareness and understanding among key stakeholders, including farmers, cooperatives, and business managers. Blockchain concepts can be complex, and without adequate digital literacy, users are unlikely to rely or engage with the technology.

Addressing this challenge involves structured training programs, awareness campaigns, and capacity-building initiatives that explain blockchain's value and limitations in practical terms. It needs to reach also the consumer, who needs to be familiar with tools such as QR code (or VR in the future), i.e. scan/understand what the labels are telling them.

3. Lack of a complete EU regulatory framework / lack of clarity

The current EU regulatory environment for blockchain, particularly in agriculture and food systems, is still evolving. There is uncertainty around **data governance, smart contract enforceability, liability, and compliance with standards like GDPR**. This legal ambiguity discourages investment and slows down its adoption.

A clearer, harmonized EU framework is needed to provide legal certainty, define responsibilities, and support secure, compliant blockchain deployment across borders.

4. Initial setup and integration costs

Implementing blockchain solutions can involve significant upfront costs, including infrastructure, software, training, and integration with existing systems. For farmers and small- and medium-sized actors in the agrifood sector, this can be a major deterrent.

Only a low-cost technology can prove its inclusiveness in rural areas or developing countries as a majority of the agricultural households have low financial capacity – it means to use existing open source standardized solutions or other technical solutions able to reduce the investment to a minimum.

Also, targeted funding mechanisms, such as public-private partnerships or cascade funding through testbeds and sandboxes, are needed to lower the barrier to entry and support experimentation and scaling. Then, securing sufficient and sustained investment to transition from experimental pilots to full-scale deployments is the following step.

5. Integration with existing IT systems and organizations

Integration across different blockchain platforms and legacy systems posed significant barriers in pilot implementations. Many agrifood businesses already rely on existing IT systems (e.g., ERPs, supply chain management tools); blockchain solutions need to integrate smoothly with these infrastructures without disrupting operations or adding burdens, while preserving the privacy of business sensitive information and data.

This requires middleware development, well-designed interfaces, and training to ensure organizations can adopt blockchain incrementally and with minimal disruption to current workflows.

6. Interoperability – technical challenges

Blockchain systems often operate in isolation, and interoperability between platforms is limited due to incompatible technical architectures, data standards, and legal frameworks. This fragmentation prevents seamless data sharing across the agrofood value chain.

Solving this requires standardization efforts, development of open APIs, and legal agreements that ensure interoperability both technically and contractually between systems and actors.

7. Trustable data entry

Blockchains don't verify data at the point of entry — they only secure and timestamp it. So if the original input is false, incomplete, or manipulated, then the blockchain simply preserves a bad record immutably. That's why relying on blockchain alone to guarantee trustworthiness is naive — it just shifts the trust problem upstream, "kicking the can down the road" to the data providers.

Building the "input assurance layer" around blockchain is important. It means (i) strengthen the link between data and identity, e.g. using verifiable digital identities (e.g. EUDI, SSI, enterprise IDs) tying every data input to a legally accountable actor (e.g., farmer, certifier, lab) and using digital signatures or credentials to ensure data can be traced back, (ii) use verified data sources and trusted oracles, traceable and non-repudiable (so actions can't be denied later) (e.g. IoT sensors with tamper-proof hardware for temperature, GPS, humidity).

8. Data privacy and data ownership

Blockchain offers transparency and traceability benefits in the agri-food sector, but it raises unresolved issues under GDPR. Its immutability conflicts with the right to

erasure, making it impossible to delete personal data once stored on-chain. There is often a lack of informed consent, especially from smallholders who may not fully understand how their data is used. The role of data controller is unclear in decentralized systems, complicating accountability. Even

pseudonymized data can risk re-identification, especially in traceability applications.

Without clear governance, off-chain data strategies, and legal safeguards, blockchain use in agri-food remains legally and ethically problematic.



Fourth
Part

Possible futures



08

Exploring potential future developments

The **European Green Deal** aims at transforming the EU into a modern, resource-efficient and competitive economy, becoming climate-neutral by 2050.

But what will the system be like in 2050? Which role will digitalization and block-

chain technology play? The consortium, working in strict contact with experts in futures thinking, strategic foresight, social science and stakeholder engagement, posed these questions and envisaged some possible futures together with the collaboration of external stakeholders.



8.1. Futures thinking: the role of scenarios and backcasting to envision the future

The TRUSTyFOOD project involved the strategic use of both backcasting and scenario development to envision and shape the future of blockchain-enabled food systems. These methodologies, which are better clarified along the text, serve complementary roles in navigating complex, uncertain futures and translating strategic visions into actionable pathways.

Scenario development was used to explore a range of plausible futures based on current trends, tensions, and values identified in the visioning workshops carried out along the project lifespan, also considering current megatrends. Scenarios offer diverse narratives about how blockchain Technology might evolve within the agrifood system.

These scenarios are not predictions but structured explorations of what could happen under different conditions and with different driving forces. They help stakeholders anticipate challenges, identify opportunities, and stress-test strategies across multiple possible futures.

Backcasting plays a pivotal role in this process by starting with a desirable future - in this case, sustainable, blockchain-integrated food systems - and working backward to identify the necessary steps to achieve that future(s). Unlike forecasting, which projects current trends forward, backcasting allows stakeholders to break free from present constraints and imagine transformative change. The backcasting method has a number of features that make it useful in developing long-term strategies and roadmaps:

- **Goal-oriented:** it starts by defining a specific, desirable, future.
- **Reverse engineering:** rather than predicting the future based on current trends (forecasting), it works backward in time to identify the necessary steps and conditions to achieve that envisioned future (i.e. enabling conditions).
- **Pathway focus:** it emphasizes defining the pathways that will lead to the desired future. In essence, backcasting asks, "If we want to be there in the future, what do we need to do now and over the next years?"

In the TRUSTyFOOD project, backcasting was particularly valuable in Working Groups (WGs).

The overall methodology was based primarily on backcasting (Vergagt and Quist, 2011)¹⁸ and the three horizon framework (Sharpe, Hodgson, Leicester, Lyon, & Fazey, 2016)¹⁹. These methods operate by co-creating visions of idealized, desirable futures and working backwards to the present to develop concrete strategies, actions, and interventions that can be taken to realize (some aspects of) these visions.

Following this, the WGs were split into **four phases**, with phase I focusing on visioning, phase II focusing on barriers and drivers, phase III focusing on developing strategies and interventions and phase IV focusing on the consolidation and refining of the strategies into implementable actions.

¹⁸ Vergagt, P., and Quist, J. (2011). Backcasting for sustainability: introduction to the special issue. *Technological Forecasting & Social Change*.

¹⁹ Sharpe, B., Hodgson, A., Leicester, G., Lyon, A., & Fazey, I. (2016). Three horizons: a pathways practice for transformation. *Ecology and Society*, 21(2).

Phase I of the SWGs involved three visioning workshops, each centering on one of the following themes: climate change mitigation in agriculture; transparent and traceable supply chains; and sustainable, healthy, and inclusive food systems. In these workshops, participants first co-created visions of sustainable future food systems and, second, explored the role that BCT may play in those desirable futures. Following this phase, recordings, transcripts, and digital whiteboards were analyzed to develop three coherent, discrete scenarios of blockchain-enabled future food systems.

Phase II involved five workshops, each involving representatives from one of the stakeholder groups defined in *table 1* at page 11. These workshops began by discussing the visions explored in phase I and subsequently focused on the barriers and drivers related to realizing these visions.

Phase III involved three workshops focused on developing strategies to overcome the barriers identified in phase II. To provide structure to these workshops, a specific vision from phase I and specific, related barriers from phase II were presented to workshop participants.

Phase IV comprised two consensus-building workshops, one with external stakeholders and the other with internal stakeholders. The workshops were structured as co-creation sessions aimed at refining the strategies and interventions identified in Phase III for the effective application of blockchain technology in driving sustainable food system transformation.

Given the broad and conceptual nature of the initial strategies, a backcasting methodology was employed to systematically translate them into specific, actionable and implementable measures. The approach facilitated a structured pathway from envisioned future outcomes to present-day actions, ensuring the strategies were both contextually relevant and operationally feasible.

Together, scenario development and backcasting create a robust foresight framework. Scenarios stimulate critical thinking and broaden the horizon of possibilities, while backcasting anchors visionary goals in the present, guiding strategic planning and policy design. This dual approach empowers stakeholders to not only imagine but also begin to actively shape the desirable future of sustainable food systems.

8.2. The role of Megatrends in supporting the visions of the future

Megatrends are long-term driving forces that are observable now and will most likely have significant influence on the future. It is not possible to depict scenarios and envision possible futures without considering megatrends and the role they can play. JRC identified 14 Megatrends²⁰. They are not isolated events but rather interact and reinforce each other, creating a complex and dynamic global landscape. Understanding these trends is crucial to adapt to the challenges and opportunities of the future.

Without considering one by one in isolation, we can assemble them into macro-topics:

14

Megatrends identified

6

Macro-topics identified

1. Globalization and interconnectedness:

This refers to the increasing interconnectedness of economies, societies, and cultures through trade, communication, and travel.

2. Technological disruption:

This involves the rapid advancement and adoption of new technologies, including artificial intelligence, automation, and digital technologies, which can disrupt industries and reshape work.

3. Changes in education and learning:

Strictly related to topic 1 and 2 - new generations and hyperconnectivity are rapidly changing both educational needs and modes of delivery. Learning methods are evolving as well as the fundamental skills required; digital literacy is increasingly indispensable, even for groups and age classes that were previously considered excluded.

4. Climate change and environmental degradation:

This includes rising temperatures, extreme weather events, and resource scarcity, driven by pollution and greenhouse gas emissions.

5. Changes in the global economic landscape:

This includes the rise of new economic powers and the redistribution of wealth and resources. This implies growing social tensions, instability and inequality. In the same area we can include the increasing influence of new governing systems: non-state actors, global conscientiousness, social media and the internationalisation of decision-making are forming new, multi-layered governing systems and new emerging needs (e.g. decentralisation).

6. Changing values and behaviors:

This refers to growing consumption (by 2030, the consumer class is expected to reach almost 5 billion people; this means 1.3 billion more people with increased purchasing power than today). It encompasses shifts in consumer preferences, values, and lifestyles, often influenced by social and technological trends. It also necessarily implies a shift in health challenges: unhealthy food or lifestyles are turning into health burdens and need to be addressed through conscious choices.

²⁰ https://knowledge4policy.ec.europa.eu/foresight/tool/megatrends-hub_en



8.3. Three scenarios of the possible futures led by BCT

Scenario 1: Efficiency, Transparency, and Resilience

The digitization of the food system is primarily driven by market-forces.

BCT would primarily be used for business-to-business purposes such as streamlining processes and communication within complex supply chains (in line with the **Megatrend of increasing interconnectedness**) and for increasing the transparency and traceability of these supply chains (in line with the **Megatrend related to growing consumption and consumer's changing values**).

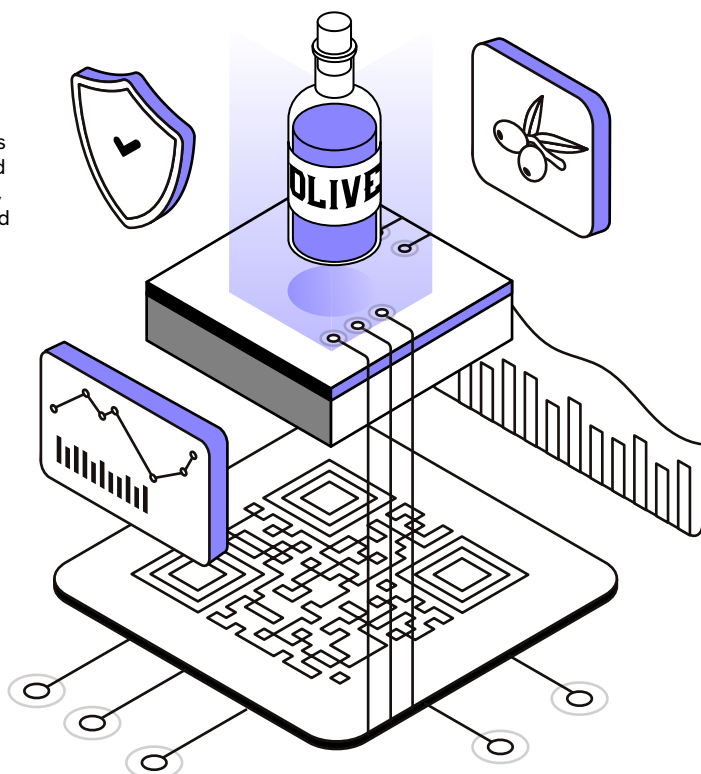
There is a high level of innovation regarding BCT (driven by private sector investment) and adjacent technologies themselves, as well as in the business models and supply chains in which these technologies are

embedded. In line with the **Megatrend "Climate change and environmental degradation"**, the market still responds to growing societal demands for increased social and environmental sustainability, for example, by using blockchain to provide additional product information.

Costs and economies of scale result in relatively large corporate actors driving the majority of adoption and innovation in this scenario. The benefits of BCT are concentrated among well-capitalized actors, leading to a food system that is technologically advanced but socially uneven (in line with **Megatrend "social inequalities and unbalances"**).

01

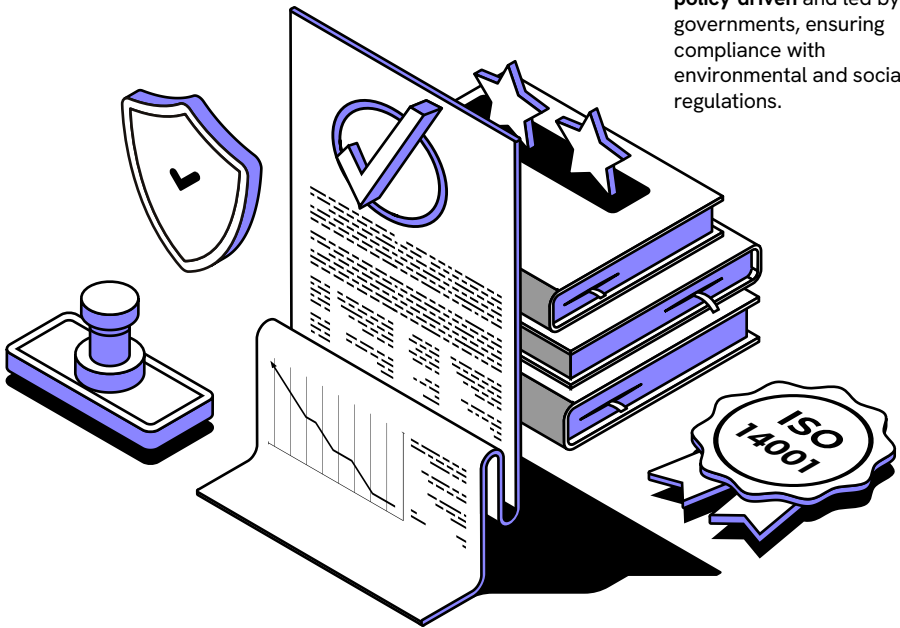
Blockchain adoption is **market-driven** and led by large corporations, boosting efficiency and transparency but widening social inequalities.



Scenario 2: Compliance and Accountability

02

Blockchain adoption is **policy-driven** and led by governments, ensuring compliance with environmental and social regulations.



The second scenario is centered around a policy-driven transformation in which governments adopt BCT to enforce environmental and social regulations. This scenario associates BCT adoption with policy instruments including EU Green Deal, Corporate Sustainability Reporting Directive (CSRD), and the EU Deforestation Regulation (EUDR).

National authorities establish common standards and terminology, promoting interoperability of national and regional blockchain systems. Due to governments driving digital transformation, the use of BCT and other digital technologies is centered around regulatory compliance: blockchain should be used to provide data to assist with complying with regulations and otherwise contribute to the transformations

sought by governments. Following this, the uses of blockchain and associated policy objectives are grounded in the values of transparency, environmental sustainability, and social sustainability (contrasting in the latter the **Megatrend on "Widening inequalities"**).

The primary use of blockchain is for recording and sharing data about the food system (with respect to products, their origins and movements, as well as data concerning environmental and social impacts). Blockchain is largely used as a back-end data layer to support the implementation of policies such as EUDR and CSRD (related to **Megatrend "Climate change"**).

This can minimize bureaucratization, or otherwise create additional compliance

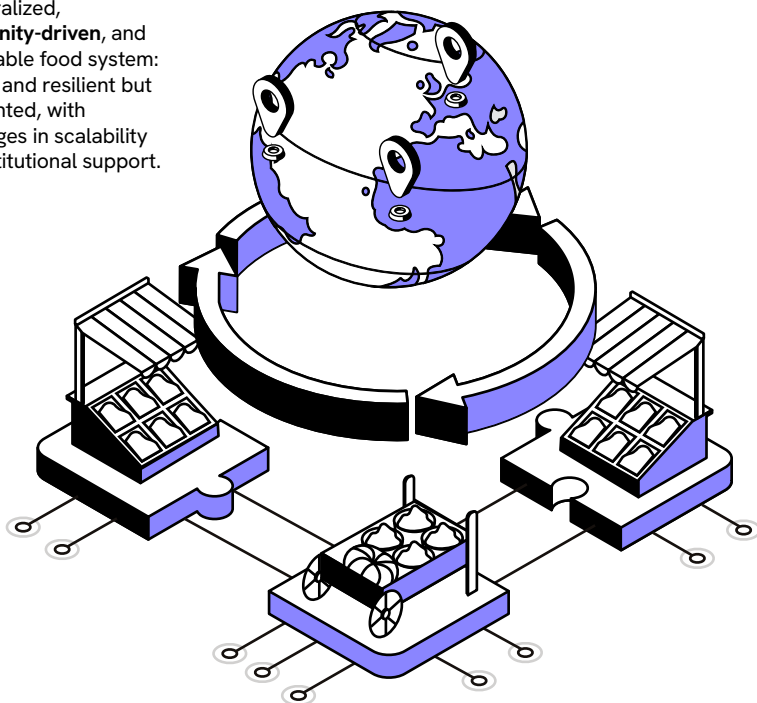
burdens and/or require rapid expansion and evolution of auditing systems. Blockchain can be leveraged to directly support transitions to sustainable agriculture by, for example, expanding Payments for Ecosystem Services (PES) markets. In line with the

Megatrend “Diversification of education and learning”, governments spearhead various educational initiatives to ensure that relevant actors are sufficiently knowledgeable about BCT and other technologies in the digital transformation of the food system.

Scenario 3: Ecologically Integrated and Place-Based

03

Blockchain adoption envisions a decentralized, **community-driven**, and sustainable food system: diverse and resilient but fragmented, with challenges in scalability and institutional support.



Digitization of the food system is primarily driven by bottom-up efforts, and it is connected to broader trends of decentralization, community empowerment (in line with the increasing influence of new governing systems and efforts to counteract the **Megatrend “widening inequalities”**), and sustainable development (in line with **Megatrend “Climate change and environmental degradation”**). This scenario envisions the adoption and use of blockchain as led by

a mosaic of small-scale farmers, cooperatives, communities, and locally-oriented, place-based companies.

Because adoption followed this pattern, the food system is diverse and, in many ways, fragmented. BCT could be used for a variety of purposes: enabling access to financing for small communities and farmers, for example through crowdfunding; token-based payments for ecosystem services, or blockchain based PGS (participatory guarantee

system) certifications; the management of resources and especially waste in line with circular economy principles; providing information to support farm- and field-level decision-making; among others.

In this scenario a variety of agricultural production systems coexist, which could be based on local, place-based, and ecologically integrated production systems such as agroecology, or high-tech systems such as CEA (closed environment agriculture), aquaponics, and precision agriculture. The driving value in this scenario is bottom-up participation and local autonomy, with the values of social sustainability, environmental sustainability, and decentralized govern-

ance playing crucial roles as well. Due to the fragmented nature of the transformation in this scenario, it contains a mixture of highly sustainable and resilient food systems and as well as less sustainable and resilient alternatives.

Yet, the localized and fragmented nature of technological innovation brings challenges in scalability, standardisation, and interoperability. Several communities lack the digital infrastructure, financial funds and/or technical support which is necessary to maintain such systems over time, and the risk of marginalisation remains if these models are not institutionally supported.

8.4. Common and different elements between scenarios

In line with the **Megatrend “Acceleration of technological change and hyperconnectivity”**, in all three scenarios, digitalisation is the basic driving force behind changes in social and economic systems, and therefore in the food system: what will change is the relative weight of the other driving forces that will influence the power of the various roles or agents, the extent of applications and the levels of interaction or interdependence of BCTs.

In terms of differences, while the first scenario sees markets as the primary agents of transformation, the second emphasizes the

regulatory state, and the third prioritizes community-led initiatives.

The scenarios also differ in terms of their treatment of values including decentralization, equity, trust, and inclusiveness. All the selected scenarios underline that the outcomes of blockchain deployment in food systems are not predetermined.

Blockchain can lead to vastly different impacts depending on how it is integrated within broader systems of governance, power, and participation.

8.5. Our convergent vision for a Blockchain-Enhanced Agri-Food System

The desirable futures envisioned by the TRUSTyFOOD Project Consortium, during the foresight process and further consolidated during the backcasting workshop, converge around a resilient, inclusive, sustainable and transparent agri-food system, enabled — but not determined — by Blockchain Technology (BCT).

These futures are not technology-driven per se, but value-driven, rooted in social, environmental, and economic priorities. BCT is considered a key enabler only if embedded in systems that serve people and ecosystems, not the reverse.

Accordingly, **the Desirable 2050 Food System** is characterized by the following shared attributes:

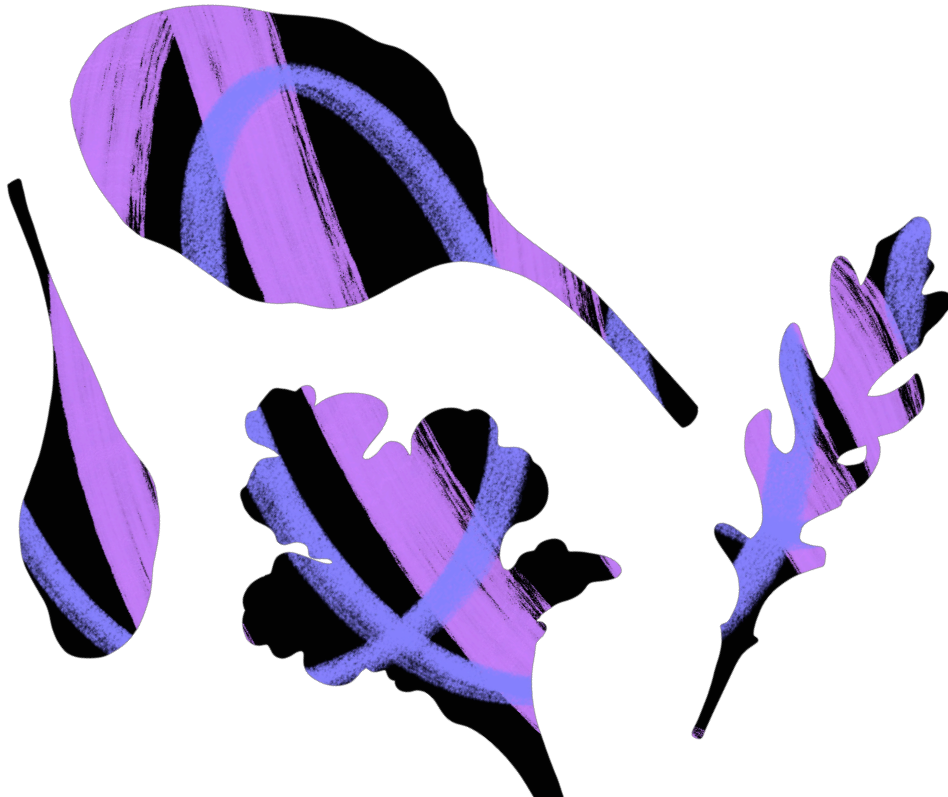
- **Interoperable digital infrastructures and human-centred design** Technological solutions — including blockchain, IoT, and AI — are fully interoperable, designed for people and adapted to different user needs (farmers, regulators, citizens). Digital tools have become accessible, intuitive, and responsive to diversity in digital skills and contexts. Augmented reality and mobile applications allow citizens to make informed choices; UX design ensures that tools are usable also by people with disabilities or low tech access.
- **Decentralized, transparent, and reliable data ecosystems** Blockchain is widely adopted as a layer for data integrity and interoperability. It ensures full traceability of food products and production practices, allowing transparent access to data across actors and borders. Information on environmental impact, origin, and quality is verifiable and available in real time. Importantly, data ownership is respected: farmers and SMEs retain control over their data and derive value from it, including access to finance or ecosystem service compensation.
- **Aligned and adaptive regulation** Regulatory frameworks are harmonized across Member States, and affiliated non member states, and anchored in clear principles of simplicity, transparency, and legal certainty. Smart contracts are legally recognized and interoperable across sectors. Regulation is adaptive and co-designed with users, avoiding burdensome complexity. Public authorities use blockchain for auditability, certification, and rapid response to food crises.
- **Empowered and digitally literate actors across the chain** By 2050, education and digital literacy are widespread across the agri-food system, from farmers and SMEs to consumers and logistics operators. Tailored programmes have ensured that women, youth, and marginalized groups are fully included, especially in rural areas. Vocational training, higher education, and peer-to-peer learning systems equip actors with the capacity to understand, rely on, and co-develop blockchain-based solutions.
- **Participatory and inclusive governance models** Governance is multi-stakeholder, participatory and distributed. Farmers' organisations, consumers, and SMEs play an active role in designing and governing digital infrastructures. Publicly funded platforms are open-source and built on democratic design principles. Blockchain has enabled new decentralized models of

certification (e.g. participatory guarantee systems) and facilitated fairer redistribution of power along the supply chain.

- **Measurable environmental and social Impact** Blockchain systems support robust, verifiable tracking of sustainability indicators, including carbon footprint, water use, land origin, and biodiversity indicators. These data feed into real-time dashboards accessible to regulators, businesses, and the public. Blockchain enables compensation mechanisms for ecosystem services and facilitates sustainable finance schemes. Consumers make choices based on meaningful, verifiable data.
- **Inclusive digital transition and fair transformation** Finally, the desirable future is one of just digital transition,

where no actor is left behind. Structural investments in rural connectivity, capacity-building, and inclusive business models have ensured that smallholders, cooperatives, and communities are not marginalized, but are active innovators and co-owners of the digital infrastructure. Blockchain is one of many tools used — only where appropriate — in support of the broader goals of food sovereignty, health, and climate resilience.

This vision provides the normative anchor for the Roadmap's action plan. The transition from current systems to these desirable futures will require differentiated pathways, depending on the interplay of technological, social, and policy dynamics — as articulated in the three scenarios and their respective drivers.



Fifth
Part

Bridging vision to implementation



09

Roadmap to 2030

To face blockchain integration within broader systems of governance, power, and participation there are some challenges which need to be overcome in the forthcoming years to achieve the 2050 conditions in line with the seven attributes mentioned above.

R&I is a critical process for innovation and progress, enabling to address current chal-

lenges and improve existing solutions to meet the evolving needs of society. Public funds, in particular, can play a crucial role in reducing financial risk associated with Research and Innovation (R&I) activities by providing a safety net and encouraging private sector investment. EU must ensure major funding streams in this field. Below the priority areas for investment are clarified.



9.1. R&I Priority areas

Starting from par. 7.1.4, we identified **three strategic transdisciplinary research areas**:

- **Capacity building and skills development,**
- **Technical needs and digitalisation,**
- **System economics.**

These areas were selected to comprehensively close the gap between technological potential and practical adoption and quickly move towards the achievement of the visions to 2030-2050 where digitalisation is confirmed as the baseline and blockchain is embedded.

First, the *‘Capacity building and skills’* area addresses the human and institutional dimensions by fostering awareness, education, and skill development among stakeholders—from farmers to consumers—ensuring that the benefits of blockchain are understood, accepted, and effectively utilized.

Second, the *‘Technical needs and digitalisation’* area targets foundational challenges such as interoperability, cybersecurity, integrated digital systems, and the creation of experimentation spaces (testbeds/sandboxes) that enable real-world validation of blockchain applications in food traceability, fraud prevention, and sustainable certifications.

Lastly, the *‘System economics’* area examines the economic impact of blockchain adoption (how blockchain can transform agrifood value chains through new business models and value chain reorganisations, equitable value distribution, administrative efficiency, and financial inclusion, particularly for smallholders).

These three pillars are interlinked and critical for ensuring that blockchain adoption in agrifood is not only technologically viable but also economically sustainable and socially inclusive by 2030 and beyond.

9.2. Action Plan

Here a selection of actions to be started in the forthcoming 5 years, divided per area with a time horizon for the expected impact. As better clarified along the text, while primarily referred to EU, it is important to highlight that – given the global trade – some actions need to be addressed in a global perspective fostering International cooperation.

This paragraph is divided into three parts:

- “WHAT” should be done (Identification of three Action Areas)
- “HOW” should be done (instruments to be used)
- Timeline

9.2.1. WHAT should be done

9.2.1.1. ACTION AREA 1 – BUILDING AWARENESS, CAPACITIES, SKILLS

Table 3

ACTION	OBJECTIVE	EXPECTED IMPACT	TIMEFRAME
Data Value	Promote understanding of data as an economic asset across the agrifood chain	Increased data sharing, more informed actors	Short-term
Communication/ Dissemination	Share best practices and real-world blockchain success stories	Faster diffusion of innovation, reduced scepticism and awareness on benefits	Short-term
Consumer Education	Build consumer literacy on credible data, digital traceability, and sustainability labels	Empowered consumers making sustainable choices	Short-term
Strengthen DIHs	Enhance DIHs’ role in training, technology transfer, and climate action using BCT	Regional tech diffusion, improved climate resilience	Medium-term
The AGENT: a new professional figure	Create new experts able to facilitate the dialogue between ICT experts and farmers/owners	Improved applications, stronger multi-actor collaboration	Medium-term

The working groups put in evidence the importance to include investment in the training of farmers, producers (technicians and managers) and consumers alike through programs dedicated to reinforcing **digital literacy**. Such initiatives ensure that they understand the value of data and possess the foundational knowledge to engage with digital and blockchain-enabled tools effectively.

Key personnel should be educated on what blockchain can and cannot do to ensure that the technology is applied effectively. An upfront training program for farmers and businesses is what can be suggested as a key success factor in every initiative EU embark on, while for consumers could also be based on online solutions (e.g. blogs, ...).

Equally important is **raising awareness** of the benefits and limitations of blockchain applications, which can drive informed participation across the value chain. To promote informed participation across the value chain—**communication actions** must be targeted, inclusive, and evidence-based. Resources should be allocated to: 1) Story-telling through real-world use cases (share success stories and lessons learned from blockchain pilots or implementations in agrifood); 2) grassroots stakeholder work-

shops and demonstrations (organize interactive workshops, live demos, and field days with farmers, cooperatives, processors, and local authorities), use sandbox environments or digital twins to show how blockchain works in practice; 3) Consumer educational media campaigns.

Such activities should be supported by governments and led by DIHs, associations, cooperatives, Producers' Organizations, consumers' associations.

The unexploited **role of DIHs** strongly emerged during focus groups and was valorized along the workshop carried out in April 2025 together with 8 DIHs from 7 countries.

A specific TRUSTyFOOD White Paper has been dedicated to exploit both the professional figure of the AGENT, as well as of DIHs in training, technology transfer, and climate action using BCT. Train-the-trainer programs should be organized for DIHs, but also as Helpdesk - local hub which connects stakeholders - hub which provides support to apply to cascade funding calls or making them serve as testing centers.

The role of DIHs is border line between technical and educational areas, since their intervention is required at both levels.

16

workshops
carried out

9.2.1.2. ACTION AREA 2 – TECHNICAL NEEDS / CHALLENGES / DIGITALISATION

Table 4

ACTION	OBJECTIVE	EXPECTED IMPACT	TIMEFRAME
Experimentation spaces	Launch local multi-actor experimentation zones and cascade calls	Faster innovation, localized testing before scale-up	Short-term
Support DPP Pilots	Pilot Digital Product Passports for key agrifood chains	Foundation for traceable and sustainable product flows	Short-term
Improve UX	Simplify interfaces for farmers and SMEs	Broader adoption by low-digital-skill users	Short-term
Finance to farmers	Feasibility to unlock access to new source of finance for EU farmers	ensure EU farmers have access to proper financing	Short-term
Certifications	Clarify which are the certifications that would benefit more from having blockchain data	Wider access to certifications also by farmers and smallholders; obtainment and maintenance simplified; certifications verifiable	Short-term
Standardisation & Interoperability	Develop EU-wide data standards and ontologies for agrifood blockchain systems	Seamless integration of systems, cross-border data sharing	Medium-term
Integrated Systems (BCT + IoT + AI)	Enable real-time, verifiable data flow for traceability, safety, fraud prevention	Resilient and transparent agrifood chains	Medium-term
Open-Source Solutions	Develop models for funding, maintaining, and scaling open-source BCT tools	Greater collaboration, lower barriers for SMEs	Medium-term
Cybersecurity, Data Ownership & Governance	Create secure frameworks for data sharing with clear governance rules	Enhanced trust, protection of sensitive farm-level data	Short-term
Move Toward Credible Data (AI + BCT)	Validate farm-to-fork data using AI verification and blockchain anchoring	Verifiable data for consumers and auditors	Medium-term
Improve Rural Digitalisation	Extend infrastructure and training in rural regions	Inclusion of underserved communities	Long-term

In this list of intervention lines, **two main sub-areas** are identified:

9.2.1.2.1. Integration, standardisation and interoperability

The first need is to provide an answer to the food supply chain players request for **democratized design** and implementation. On June 5th 2022, the EU adopted “the new European innovation agenda,” which aims to create interconnected, more inclusive, and more efficient innovation ecosystems in the EU. To achieve this goal, experimentation spaces (e.g. living labs, regulatory sandboxes, test beds or safe harbors) could facilitate the deployment of disruptive technologies. Therefore, improving the general conditions for “**experimentation spaces** for deep tech innovations” is one of the strategic key priorities of the EU innovation agenda, fostering also International cooperation.

Definition of experimentation spaces

Focusing on the BCT development phase first, the introduction of simplified regulatory environments (experimentation spaces) could be useful, allowing its effectiveness to be tested. Experimentation spaces provide controlled and safe environments for testing innovative solutions where regulatory clarity and or technological feasibility hasn’t been established yet. The EU distinguishes three main experimentation tools with different motivation and can be seen as complementary:

- **Testbeds:** Used for development, testing and upscaling of product or services. Usually focus on technology and do not necessarily have a regulatory component.
- **Living Labs:** Experience and co-creation focused environments that involve users and citizens to prototype, develop, test and upscale innovative solutions.

- **Regulatory sandbox:** Controlled environment that allows for real-world testing of innovations under market conditions with temporary loosening of regulatory rule while still safeguarding regulatory objectives such as consumer protection. The goal is to achieve legal security and allow for regulatory learning.

Additionally, safe harbors can serve as additional legal provision that protect from liabilities under certain conditions. They are however more common in the U.S.

Current state of blockchain experimentation spaces

The EU has recognized the value of experimentation spaces as adoption drivers for blockchain technology and in 2023 established the DLT Pilot Regime and the European Regulatory Sandbox. Despite their respective success, they do not fully address the needs of the agri-food sector.

The DLT Pilot Regime focuses on finance applications exclusively and enables testing of DLT for trading and settlement of tokenized financial instruments. The European Regulatory Sandbox on the other side is open to any sector and focuses on regulatory dialogue between innovators. However, what is not in the scope is the development and testing of blockchain-based (agri-food) applications.

Additionally, INATBA identified one weakness on the setup and operation in the case of interoperability regulatory sandboxes that is only limited to public entities and exclude key innovators such as SMEs, end-users or technology providers who might benefit the most from participating in them.

To address these limitations, a **multi-stakeholder, public-private partnership approach** is essential. The design of experimentation spaces should not be restricted to public entities alone but actively involve a broad range of stakeholders along the

agri-food supply chain such as farmers and food producers, regulators, enterprises, technology providers, researchers, standardization bodies, etc. In particular, within the experimentation space, end-user involvement is critical as their feedback ensure the developed solution meets their needs.

Another difference would be that multiple technologies such as blockchain in combination with AI or IoT would be tested as agrifood supply chains are not digital only and require physical data from the real-world.

Such a collaborative and holistic approach would ensure scalable and replicable solutions that would reflect the real-world complexity of agri-food sector.

The previous work of TRUSTyFOOD through the engagement of a high number of stakeholders has set the right foundation for experimentation spaces. In the future, the network created by TRUSTyFOOD and other EU projects involving blockchain and agriculture could be used to discuss with them the design of suitable experimentation spaces and subsequently the **development, testing and deployment of such solutions** for the agri-food sector.

Most importantly, the deployment of blockchain must be rooted in genuine co design with micro and small producers, not imposed top-down by technology providers. Only when solutions are built with a genuine understanding of constraints—daily workloads, cash flow limits, digital literacy gaps—can blockchain deliver real value and unlock its potential across the full spectrum of smaller agri-food operators.

From the technical perspective, the recommendation is to focus on **modular, user-friendly, low-cost applications** tailored to real operational needs. It requires integration with familiar technologies (such as

mobile apps, QR code scanning, or minimal IoT devices), clear demonstration of tangible benefits, and strong support structures including training and accessible onboarding.

Accordingly, the following should be taken into consideration for investments:

- **Open-source solutions** should be mainly exploited, including the open source capabilities delivered by EBSI. Indeed, open-source blockchain platforms can be used as foundation to reduce development and licensing costs, making it feasible for SMEs, cooperatives, and even smallholder farms to experiment with blockchain without major upfront investment, thus lowering entry barriers. This is especially important in agriculture, where margins are thin and digital uptake is often limited by cost sensitivity and lack of technological expertise. The focus should be on creating non-differentiating services within open-source community, that can be used by each individual player to create market-differentiating solutions on top of it.
- **Improve User Experience (UX):** Many blockchain implementations in agrifood are hampered by overly complex technical frameworks that intimidate end users. The technical complexity inherent in blockchain systems creates barriers for companies with low digital maturity. Lessons learned call for simplification of the user experience—developers must abstract technical details and build intuitive interfaces, templates, ready-to-use solutions. By hiding complexity behind user-friendly applications, businesses can accelerate adoption and integration into existing processes.
- **Balance formalization and flexibility:** Blockchain's design often enforces strict process formalization, which can

be counterproductive in a traditionally flexible and dynamic agrifood environment. Overly rigid blockchain protocols may restrict the agility required in daily operations and supply chain adjustments. A key lesson is that a balance must be struck between the necessary formalization for security and traceability, and the operational flexibility that agrifood businesses need. Adopting customizable models could address these concerns, ensuring blockchain enhances rather than hinders business processes.

Afterwards, bridging the gap between experimental projects and operational, scalable systems in a live environment is fundamental. The deployment approach should be defined well in advance of its implementation.

Another critical line of action for future research and innovation involves **interoperability and standards**. One of the biggest topics often discussed across various domains, including agri-food, is the need for every system to communicate with every other system, emphasizing “smooth” or “seamless” exchange and interoperability. However, in reality, this is not always necessary, nor is it realistic. This is the reason we need selective interoperability frameworks that would focus on the specific data flows that actually matter.

For example, the use cases might include situations where a food safety issue requires rapid tracing back to its source, when sustainability claims need verification, or when particular compliance documentation must be exchanged between supply chain partners and government bodies such as those related to food safety. Another need is practical guidance that bridges the gap between existing technical standards, which may not be relevant to the agri-food sector, but truly addresses the existing operational gaps in agricultural operations.

Current blockchain standards like ISO/TC 307 and others are solid foundations, but a farmer or food processor shouldn’t need to become a blockchain expert to understand how these apply to their daily operations, nor is it a trivial task for technology providers to study and translate the best practices that could fit the case. The stakeholder community requires clear implementation pathways or sector-specific implementation guidance that demonstrate how blockchain supports, for example, environmental monitoring in the agri-food sector or integrates with existing reporting systems or requirements. Promoting cross-border collaboration on blockchain standards is important as well.

The technical infrastructure must also recognize that agri-food businesses already have significant investments in existing systems (from IoT sensors monitoring soil conditions to robotics and enterprise software managing inventory and logistics). Rather than forcing companies to choose between their current technology stack and blockchain benefits (which is often presented overly optimistically, disregarding the good knowledge of the ROI and other implications), we need solutions that work alongside what’s already in place or truly fill the gap and **support technology-agnostic deployment**.

This means building connections that allow blockchain applications to enhance existing solutions and technologies without disrupting proven operational workflows. This would not be fully feasible without the groundwork laid through interoperability and standardization efforts.

Yet, concrete actions should be taken to **expand piloting the Digital Product Passports (DPPs) to agrifood supply chains**. The EU is already piloting DPPs in textiles, electronics, and batteries under the Circu-

lar Economy Action Plan. Extending pilots to high-impact agri-food chains (e.g. dairy, wine, meat, olive oil) is a logical next step, especially given rising regulatory pressure for food traceability and ESG reporting. By aggregating key product data (origin, handling, certifications, transport conditions) in a digitally accessible format, DPPs enhance traceability, which is essential for food safety, quality assurance, and fraud prevention; for consumers, retailers, and authorities, this means more verifiable, actionable data. At the same time, DPPs enable the transparent tracking of environmental and sustainability metrics — such as carbon footprint, pesticide use, water consumption, and certification status — across the entire agri-food supply chain. This directly contributes to monitoring progress toward EU climate and food sustainability goals, and combats greenwashing by making claims verifiable. Also, focusing on circular economy outcomes (enabling reuse, recycling, and waste reduction) by making product and process information accessible and verifiable, DPP ensures consistency with the EU's broader sustainability strategies.

Finally, **less explored areas (blockchain for certification and finance to farmers) should be better investigated.**

9.2.1.2.2. Data ownership, credibility and protection in distributed systems

A crucial point concerns **data protection** in distributed systems. Using blockchain in the proper way involves handling a large volume of data—often sensitive—related to production processes, product quality, environmental sustainability, and traceability. It is therefore essential that the adopted solutions strictly comply with privacy regulations, such as the GDPR, and that they are designed following the “privacy-by-design” principle.

Another important point is data collection and sharing. Farmers cannot be expected to ensure data integrity without appropriate compensation or support.

Invest in guaranteeing the **credibility of data**: it remains a critical bottleneck. Despite the growing deployment of digital tools and data-driven solutions, many stakeholders—from farmers to regulators and consumers—continue to face challenges in trusting the accuracy, integrity, and provenance of digital records. Inconsistent data standards, manual data entry, fragmented systems, and lack of transparency often result in unreliable or unverifiable information, undermining the effectiveness of digital traceability, certification, and quality assurance mechanisms. Blockchain technology offers a promising solution by enabling tamper-proof, time-stamped records and decentralized verification.

However, for blockchain to deliver truly credible data, it must be combined with other technologies such as IoT sensors for automated data capture, redundant sensors capturing the same metrics for verification purposes, AI for automatic error detection and data validation, and interoperable standards for seamless data exchange across platforms. Coupling IoT with blockchain significantly improves real-time tracking of auditable/accountable data and consumer verification. Anyway, due to the nascent market, many IoT manufacturers do not invest in dedicated BC hardware, and do not offer a broad offering of sensors with signature capabilities (only temperature sensors and a few others), creating a weakness in the BC infrastructure. An IoT market able to support the growing demand for sensors (and automation) must be encouraged.

The provenance of reliable data must be verifiable – which implies the mandatory integration of a digital identity framework

that all stakeholders can accept trust (EUDI is the only possible candidate).

Public policy must recognize blockchain as a KET (**key enabling technology**) and facilitate its connection with data federation infrastructures and other digital tools already in use, such as IoT systems, ERP platforms, MES systems, and artificial intelligence solutions. Although blockchain is widely known for ensuring data authenticity and permanence, its role as a foundational component of digital infrastructure goes far beyond safeguarding data. Increasingly, blockchain is being recognized as a pivotal technology that connects and empowers various elements within complex digital ecosystems. Its integration with technologies like IoT, artificial intelligence, and enterprise systems is driving progress in

areas such as automation, seamless interoperability and innovation. As a result, **blockchain is evolving into a central pillar of the digital economy, rather than merely a tool for secure record-keeping.**

While **the reinforcement of digital infrastructure in rural areas** is primarily a matter for policy and investment (e.g., under the CAP, Cohesion Policy, or Connecting Europe Facility), targeted R&I actions can still support this transition. These include piloting decentralized service models, exploring innovative approaches to last-mile connectivity, and developing user-centered digital tools tailored to rural needs. Nonetheless, the foundational infrastructure and institutional support (e.g., competence centres, DIHs) must be prioritized as part of national and regional digitalization strategies.



9.2.1.2. ACTION AREA 2 – TECHNICAL NEEDS / CHALLENGES / DIGITALISATION

Table 5

ACTION	OBJECTIVE	EXPECTED IMPACT	TIMEFRAME
ROI assessment	Demonstrate return on investment from BCT applications	Justification for private/public adoption and funding	Short-term
Admin burden reduction	Develop BCT-based tools and methodologies that automate reporting, certification, audits	Cost savings for farmers and SMEs, auditors and authorities	Short-term
New Business & Value Chain Models based on BCT application in the agrifood sector	Analyse decentralized agrifood value chains using blockchain	New forms of cooperation, better resilience	Medium-term
Fair value distribution	Analyze and promote equitable benefit-sharing along the chain	Social sustainability, reduced market asymmetries	Medium-term
Trade-off analysis	Quantify savings and efficiencies for public bodies (e.g. CAP monitoring)	Informed policymaking/ governments on potential cost reductions	Medium-term
Financial inclusion and access	Design and test BCT-based microcredit, insurance, and financing tools	Empowerment of smallholders and underserved farmers	Medium-term

As made evident by our analyses (par. 6.1.3), the use cases analyzed and the experiences reported by stakeholders were referable to pilots, mostly implemented as part of nationally or European funded projects. This did not allow the project to arrive at firm evidence regarding the consequences related to blockchain application in the agrifood sector in the medium term in terms of ROI (does blockchain lead in the long term to a reduction in costs?), efficiency (does blockchain lead to an improvement in work?), business and value chain models and governance (e.g. elucidate governance structures and inter-organizational relationships; clarify if blockchain has the potential to change the current dynamics between actors, leading to more efficient partnerships and better decision-making throughout the entire chain, or improvements are due to general digitisation and/or improved data sharing; clarify which actors will bear the costs associated with the collection, validation, and inputting of high-quality

data at farm level). In particular, strategic interactions between actors in the agri-food sector for blockchain adoption remain underexplored, necessitating a multi-actor perspective to comprehensively examine the supply chain and its participants.

The investigation into collaborative arrangements and strategic alliances to expedite blockchain diffusion in remote rural areas, recognized for their resistance to innovation, offers a captivating avenue for research on social and economic development, along with understanding the leadership's role in governing adoption.

Future research and innovation initiatives should explicitly demonstrate measurable operational efficiency gains for farmers and smallholders, including: Simplification of audits and inspections, Streamlining of certification renewal processes, Reduction of payment delays from buyers through the use of smart contracts.

9.3. Priorities and potential impact under different scenarios

The actions listed above may have drastically different impacts depending on whether everything proceeds business-as-usual or whether different conditions (scenarios) arise that change the contexts for the development, diffusion and adoption of BCTs.

Here is the crosswalk table that shows the alignment between each proposed action and the three scenarios developed in the TRUSTyFOOD project, indicating the level of consistency and strategic relevance with respect to each scenario.

Here are the distinctive features of the three scenarios:

- **Scenario 1 - Efficiency & Transparency** - **Market-led:** prioritizes scale, efficiency, and competitive advantage. Focuses on innovation ecosystems, pilot testing, traceability tools, ROI.
- **Scenario 2 - Compliance & Accountability** - **Policy-driven:** driven by public standards, regulations, and incentives. Emphasizes capacity building, compliance mechanisms, and institutional integration.
- **Scenario 3 - Ecologically Integrated & Place-Based** - **Community-led:** requires adaptability, inclusion, and decentralisation. Actions should focus on empowerment, open tools, training, and social innovation.

In general, the action list rightly emphasizes technical and policy dimensions, yet inclusive governance — a cornerstone of Scenario 3 — remains underdeveloped. Concerning this point a suggestion could be to consider adding concrete actions on “polycentric governance models”, such

as: data cooperatives, where farmers and SMEs retain control over their data and its value; citizen panels to deliberate and set priorities for public R&I investments; and a strengthened role for farmers’ organisations, not only as stakeholders but as co-managers of BCT infrastructures and rules. These elements are essential to ensure that digital transformation is democratically governed and socially embedded.

Given that scenarios may occur simultaneously in different areas (e.g., where the market leads, or where public policy drives) and that different national or regional contexts will have a mix of distinguishing characteristics, this table offers some useful insights for defining priorities based on the regional context or specific production chain. This highlights trade-offs and helps decision-makers prioritize investments.

Table Legend:

Green - prioritized

Light blue - secondary

Orange - Not prioritized

ACTION	SCENARIO 1	SCENARIO 2	SCENARIO 3
Testbeds / Regulatory sandboxes	Strongly enabling	Strongly enabling	Useful only if inclusive and simplified
Piloting Digital Product Passports (DPP)	Enabling innovation	Supports policy goals	Relevant only if adapted to local certification (e.g. PGS)
Standardisation and interoperability	Promotes scalability	Facilitates integration	May hinder flexibility and local diversity
Blockchain + IoT + AI integration	Core for optimisation	Key for compliance and monitoring	Depends on infrastructure availability
Open-source blockchain solutions	Less attractive to large corporates	Public-good orientation	Crucial for local adoption and affordability
Cybersecurity & Data governance frameworks	Secondary role	Essential for trusted systems	Important for fair access and data rights
User-friendly interfaces for farmers and SMEs	Necessary for uptake	Enhances inclusiveness	Empowers low-digital-skill actors
Digital infrastructure in rural areas	Not a core driver	Key enabler for compliance	Foundational for inclusion and participation
Training & digital literacy (via DIHs, AGENT)	Lower priority	Supports capacity-building	Essential for empowerment and autonomy
Consumer education on data, labels, traceability	Supports market trust	Aligns with policy tools	Enables value-based consumption
Smart contracts for automated compliance	Not central	Highly relevant	May not fit with informal or trust-based systems
Microfinance and insurance via blockchain	Niche application	Policy-dependent	High potential for smallholder empowerment
ROI analysis and reduction of admin burden	Business case support	Helps justify investment	Less relevant in non-monetised or cooperative systems
New business/value chain models (decentralized)	Not aligned with incumbent interests	Possible under strong policy direction	Strong fit with cooperative/ community-led systems
Enhanced consumer-producer transparency	Key to differentiation	Reinforces regulatory trust	Aligns with local identity and narrative
Support for cooperatives and local networks	Not prioritized	Secondary role	Central for bottom-up transformation
Tokenisation of ecosystem services / PGS certification	Outside business focus	Emerging policy interest	Key for sustainability transitions
Alignment with EU policies (EUDR, CSRD, EBSI, etc.)	May be viewed as burdensome	Strategic anchor	May require institutional mediation for uptake

9.3.1. HOW it should be done: funds and resources to leverage

Different funding mechanisms and instruments could be activated to support the actions and priorities reported above:

1. European Union's Framework Programme (FP) for Research and Innovation (R&I)

The next Framework Programme (FP10 - 2028-2034) is under definition; a lot of consultations are ongoing, and a lot can be done in this regard.

2. Horizon Europe

Horizon Europe is in closure (2027); however the last Topics could be impacted by this Roadmap.

Most Relevant Calls / Pillars:

Cluster 6 – Food, Bioeconomy, Natural Resources, Agriculture and Environment

- ▶ Often includes digital technologies (incl. blockchain) for traceability, circular value chains, or transparency in food systems.
- ▶ Focus on multi-actor approaches (scientists, tech providers, farmers, SMEs).

Cluster 4 – Digital, Industry and Space

- ▶ For enabling technologies such as blockchain, IoT, AI.
- ▶ Cross-sectoral projects on data spaces, interoperability, and cybersecurity.

Policy suggestion: include blockchain-focused topics under Clusters 6 & 4.

2.1. Cascade Funding (FSTP – Financial Support to Third Parties)

[Smaller grants for startups, SMEs, or researchers to test, pilot, or demonstrate blockchain solutions in real settings]

Policy suggestion:

- Increase the number of R&I programmes and related Topics which include FSTP
- Co-finance such programmes to de-risk entry.
- Exploit the potentialities of DIHs as Help-desk - local hub which connects stakeholders – hub which provides support to apply to cascade funding calls.

2.2. European Partnerships (within Horizon Europe)

Sustainable Food Systems Partnership (launched 2024): R&I on food security, sustainability, and health.

- ▶ Agriculture of Data: Data-driven agriculture, precision farming.
- ▶ BIOEAST Initiative (for Central and Eastern Europe): Rural and agri-food transition.
- ▶ Participation can be supported by national co-funding schemes.

Policy suggestion: exploit this channel

3. Digital Europe Programme (DEP)

- ▶ Blockchain is included under digital technology investments (along with AI, cybersecurity, cloud).
- ▶ DIHs can serve as testing centers or trainers for blockchain.

Policy Suggestion: Support local agri-food DIHs to support local players with blockchain Reinforce Digital Innovation Hubs (DIHs) or Testing and Experimentation Facilities (TEFs) in agri-food, which may host or test blockchain applications.

4. European Regional

Development Fund (ERDF)

- ▶ Use to co-finance pilot infrastructure, Living Labs, or regional blockchain platforms.
- ▶ Align with Smart Specialisation Strategies (S3) related to digitalisation of agri-food.

Policy Suggestion: Prioritize blockchain R&I in the regional S3 plan and use ERDF to build support infrastructure or regional traceability platforms.

5. Operational Groups (EIP-AGRI):

- ▶ Multi-actor projects (farmers, tech providers, researchers).
- ▶ Can fund blockchain pilots for farm traceability, smart contracts, or certification systems.

Policy Suggestion: Facilitate the creation of EIP-AGRI Operational Groups to pilot blockchain on real farms or food chains.

6. LIFE Programme

- ▶ Focused on climate, environment, circular economy.
- ▶ Blockchain use for monitoring, carbon traceability, or supply chain transparency in sustainable agri-food systems.

Policy Suggestion: facilitate access

7. European Blockchain Services Infrastructure (EBSI)

- ▶ EU-led initiative to develop cross-border public sector blockchain services (e.g. credentials, traceability, certification).
- ▶ Pilots exist in product tracking, carbon credits, and trusted notary systems.

Policy Suggestion: Align local pilots with EBSI nodes or use-cases. Co-develop projects involving public authorities, food certifiers, or cooperatives.

8. National and Regional R&I Funds

Policy Suggestion: National funds may co-finance EU projects or fund domestic R&I in blockchain applications in agri-food sector.

9. Interreg Euro-MED

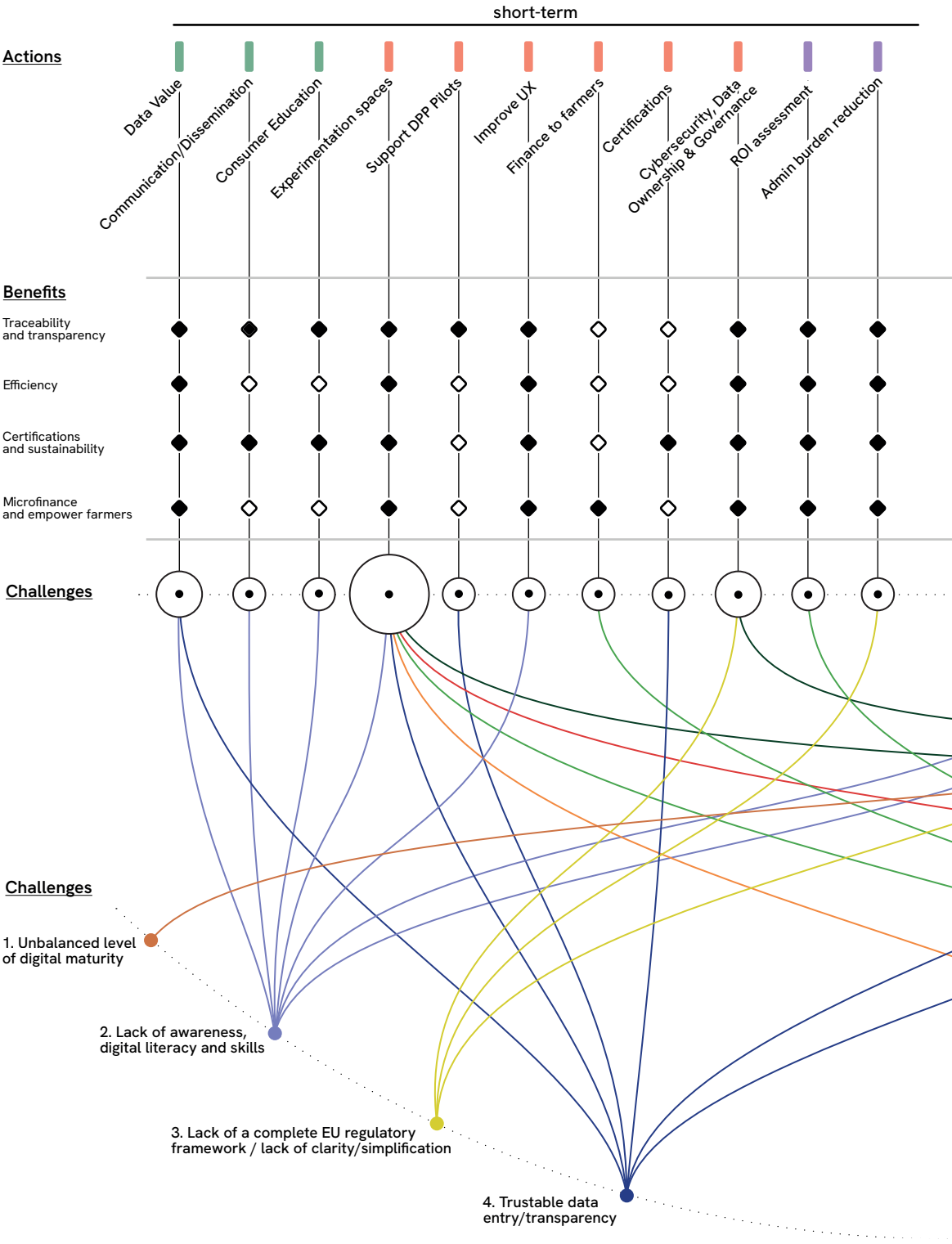
It supports projects, initiatives and policies related to climate change and the environment.

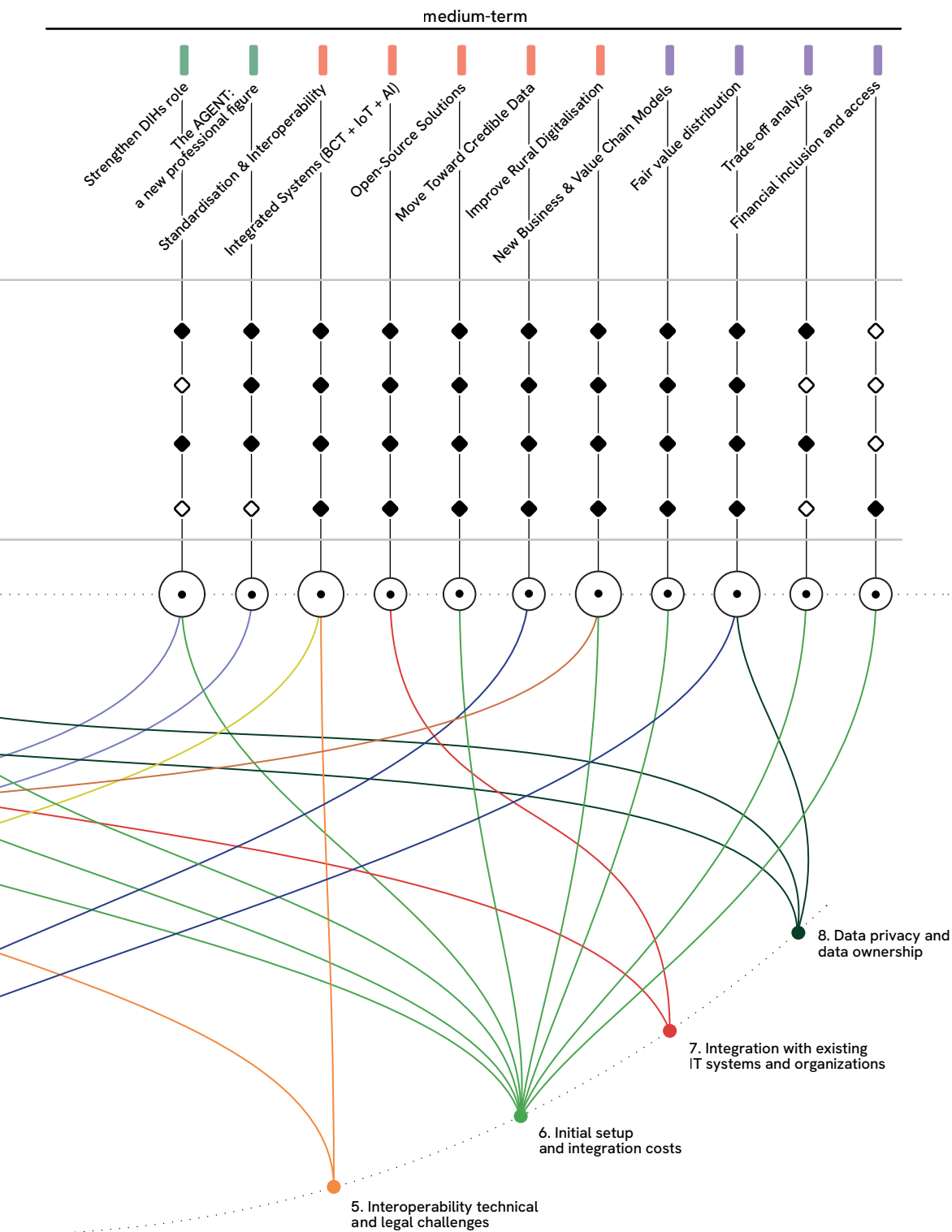
Policy Suggestion: Funds should concentrate in particular on Priority 1 – A Smarter Mediterranean and Priority 2 – A Greener Mediterranean

10. Africa Initiative III

In 2025 it allocates €500.5 million across 24 calls for proposals, aimed at advancing shared priorities between Africa and the EU.

LEGEND ACTION AREAS Action Area 1 Action Area 2 Action Area 3





9.3.3. Potential impact

Pilot projects analysed showed potential for increased efficiency, reduced fraud, and enhanced consumer trust. Quantifiable impacts on farmer income are harder to generalize but could stem from improved

market access, premium pricing for certified sustainable products, and reduced transactional costs. Environmental benefits arise from better monitoring of resource use and verifiable sustainability claims.

9.4. Recommendations

Blockchain represents a strategic technology for addressing the challenges of food security, supply chain transparency, and sustainability. Its application, although the hype around it, has not yet taken off. It does not mean that the blockchain technology does not have chances. On the contrary, in forecasted markets blockchain application in the supply chain traceability is expected to grow strongly (from 2.9 USD Billion to 44.3 in ten years). In analysing blockchain history in the last years, the TRUSTyFOOD consortium found itself having to deal with the thought of Donald Norman who controversially stated: **“technology first, needs last”**²¹, arguing that revolutionary technological advancements, those that drastically alter society, are often driven by the invention of new technologies, not by pre-existing user needs. Norman distinguishes between two types of innovation: radical breakthroughs that introduce entirely new solutions and incremental improvements to existing ones. In essence, Norman’s argument challenges the traditional view that innovation is primarily driven by identifying and fulfilling user needs. He suggests that a more accurate model is one where technology emerges, its potential is explored, and then, through a process of refinement and adaptation, it becomes aligned with human needs

Blockchain in agri-food sector is in this second phase: failures helped in understanding more the real needs of the supply chain. Its

success, in the forthcoming future, depends on the ability of institutions to create an enabling context in which farms, companies, consumers, and technologies can converge covering existing challenges toward a more digital, collaborative, and resilient agri-food ecosystem. Some recommendations follow.

9.4.1. Diversifying the approach for type of supply chain actor

Blockchain offers transformative potential for farms and enterprises, but it comes with its own set of challenges of different nature: legal, technical/at the foundation, cultural and economic. Some of them have an equal impact on all actors in the supply chain, while in other cases they have a greater impact on the weakest links in the supply chain (farmers and smallholders). In future implementation actions this unbalance needs to be solved, to ensure inclusive participation and equitable access to blockchain benefits to all the actors of the agri-food system, indiscriminately.

9.4.2. Acting now

Our investigations and findings clearly revealed that blockchain, when combined with supplementary digital tools and applied in a stakeholder-driven and systemic way, serves as a valuable enabler for revolution across various dimensions of the food system. Such dimensions include traceability and transparency, fraud prevention and authenticity, operational effi-

44.3

USD Billion in
ten years

²¹ Norman, Donald. (2010). Technology First, Needs Last: The Research-Product Gulf. interactions. 17. 38-42. 10.1145/1699775.1699784.

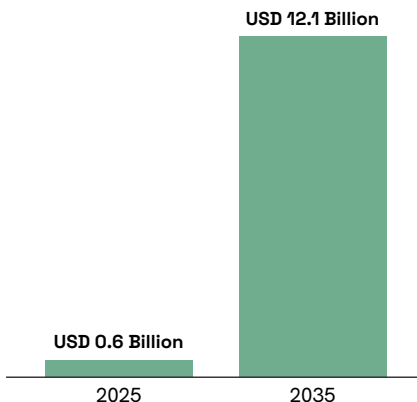
ciency and reduced waste, compliance with regulations and certifications.

Quantifiable impacts on farmer income are harder to generalize but could stem from improved market access, premium pricing for certified sustainable products, and reduced transactional costs. Environmental benefits arise from monitoring of resource use and verifiable sustainability claims. While real needs start emerging, numerous **challenges previously mentioned** do not allow for now the full exploitation of this potential and it **opens the door for different kind of risks**:

1. Ceding leadership in agri-digital innovation to global rivals

Blockchain forecasted market size in forthcoming years is impressive (see figure). The scale and rigor of our desk research and stakeholder engagement reveals a critical opportunity: Europe stands at a decision point where strategic R&I investment can position us as the global leader in responsible blockchain adoption for sustainable food systems, or we risk falling behind regions that are moving more decisively. Globally, geopolitical rivals (e.g., China, U.S., UAE) are investing heavily in blockchain for food systems and are already pi-

BLOCKCHAIN IN AGRICULTURE AND FOOD SUPPLY CHAIN MARKET



loting blockchain-based food traceability and agricultural finance platforms. Without investment, the EU will cede leadership in agri-digital innovation, losing its competitive edge in global agri-export markets becoming dependent on foreign platforms and standards, undermining sovereignty and market influence.

This could result in a long-term strategic disadvantage in a sector where innovation is increasingly linked to data governance and digital trust. Building on the capabilities created through EUBOF, EBSI, European Regulatory Sandbox, could further enhance EU's position in the blockchain space globally.

2. Weakening food safety and crisis response

Blockchain has the potential to significantly improve food safety and crisis management by enabling secure, tamper-proof traceability from farm to fork. Without greater investments in digitalisation and on this technology, the EU remains reliant on fragmented, slower, and often paper-based systems that can delay responses to food contamination, disease outbreaks, or fraudulent practices especially to the detriment of high-value products such as organic, protected designations of origin, etc. The inability to access accurate, real-time data across the supply chain compromises both consumer safety and regulatory oversight. This weakens the EU's ability to respond to future crises effectively and maintain consumer trust in food systems.

3. Widening the digital divide in rural Europe

The uneven pace of digitalisation across Member States and regions threatens to deepen the existing digital divide, particularly in rural and remote farming areas. Delayed support for blockchain deployment in agriculture risks further marginalising regions already struggling with connectivity and innovation uptake.

This not only undermines territorial cohesion but also limits access to modern digital tools that could provide benefits and open new markets for small and medium-sized farms. Without targeted support, rural areas may be excluded from the benefits of the digital and green transitions.

4. Missed opportunity for green and transparent food systems

The Farm to Fork and Green Deal objectives depend on accurate, transparent, and verifiable data on sustainability metrics. Blockchain provides the infrastructure to track carbon footprints, pesticide use, water efficiency, etc., across supply chains. Without blockchain, progress on climate and sustainability goals may be inefficient or unverifiable since data collection may remain fragmented, unverifiable, or susceptible to greenwashing. This weakens the EU's ability to measure progress, enforce standards, and build consumers confidence. Delaying adoption also risks losing first-mover advantages in creating value-added sustainable products and services across the agri-food chain and empowerment of farmers and smallholders.

9.4.3. Taking action both at the regulatory level and at the R&D level

To effectively address the challenges at hand, it is essential for decision-makers to act on two complementary fronts: regulatory policy and research and innovation (R&I).

Regulatory action provides the necessary framework, setting clear standards, incentives, and long-term signals that guide global market behavior and investment.

Without this structure, efforts risk being fragmented or misaligned with societal goals. At the same time, R&I plays a critical role in identifying and overcoming technical and systemic bottlenecks that hinder progress. Actions driven by R&I can unlock new pathways, reduce costs, and increase the feasibility of ambitious policy targets. Policies alone cannot deliver results if the solutions they depend on remain undeveloped or immature. Similarly, technological advances cannot reach their potential without enabling policies. Therefore, a dual approach ensures coherence between what is required and what is possible. Aligning regulation and innovation creates a powerful synergy that accelerates transformation. Accordingly, TRUSTyFOOD provided advices at both levels, with the Policy Brief/ Recommendations and the R&I Roadmap.

The **EU's Vision for Agriculture and Food** acknowledges the strategic and economic importance of agriculture as well as food. When considering actions for blockchain implementation, we expect the policymakers to do their utmost to support the competitiveness of Europe's agri-food chain at large, including agriculture but also the largest manufacturing sector, food and drink.

9.4.4. Monitoring the process as it progresses

The monitoring phase in a Roadmap is crucial because it ensures that a strategy or plan remains relevant, accountable, and results-oriented. In particular, the scenarios highlighted the importance to integrate uncertainty and resilience: because of external shocks (e.g. geopolitical crises, disruptive new technologies) policymakers should think about actions to enable adaptation and continuous learning.

Monitoring (through KPIs) allows policy-makers:

- To track progress toward goals (allowing measurement of whether milestones are being met, identify delays, obstacles, or underperformance early)
- Enable adaptive management, as real-world conditions can change (e.g. technology, policy, funding)

- Flexible adjustments to actions, budgets, or timelines
- Informing the design of future policies or scaled-up versions

Below are reported the Milestones identified in short-time and medium-time (until 2030).

2026

- Regulatory actions in progress: Created financial/tax incentives for agrifood actors adopting blockchain in term of testbeds (blockchain is topic for R&I in future Cluster 6 and 4 calls, Life, FP10, aligns with updated regional strategies)
- Multi-stakeholder interoperability and standardisation expert group is fully operational working on interoperability frameworks and implementation guidance for agri-food sector
- Three (3) cross-stakeholder task forces established with rotating leadership (e.g., supply chain traceability, carbon credits, smart farming)
- Regulatory actions in progress: legal recognition of BCT Records; Defined lawful use of decentralized data in accordance with EU law
- Digital Product Passports for traceability and transparency of key agrifood chains and circular economy outcomes started to be piloted (CIRPASS)
- 50 pilots activated under controlled conditions (EBSI, sandboxes, Horizon programme and cascade fundings/Life/other funding instruments at regional, national, EU level, including also collaboration with non-EU countries), including multi-actor stakeholders (e.g., producers, regulators, retailers), testing modular and hybrid architectures/open source solutions, data sharing, interoperability, scalability, user experience and BCT combination with IoT and AI—starting with traceability in high-value chains (e.g. organic, PDO)

2027

- Train-the-trainer courses on BCT activated in at least 50% of established DIHs

2028

- Regulatory actions in progress: Smart contracts are recognized in agri-trade and supply chain contexts
- Regulatory actions in progress: Aligned blockchain use with Digital Product Passport (DPP), Farm to Fork, and ESG targets
- 60% of pilots scaled up at production scale
- +50 new Pilots started - diversified for type of application (traceability-transparency, efficiency, compliance to regulations/certification, access to microfinance) - activated under controlled conditions (EBSI, sandboxes, Horizon programme/Life/other funding instruments at regional, national, EU level, including also collaboration with non-EU countries), including multi-actor stakeholders (e.g., producers, regulators, retailers), testing modular and hybrid architectures/open source solutions, data sharing, interoperability, scalability, user experience and BCT combination with IoT and AI
- ROI has been measured at least in traditional BCT applications (traceability and transparency) and high value supply chains (organic, PDO, PGI), considering both pilots and cases in production stage
- Savings and efficiencies for public bodies have been quantified and published
- Focused pilot programs launched (e.g., supply chain traceability (food safety), carbon credits (climate adaptation), smart farming).
- Task force recommendations in progress in 18-24-month implementation cycles
- Publication of a set of separate technical specifications and guidelines (e.g., data exchange protocols handbook for agri-food).
- Farmers, smallholders and consumers have been empowered in their digital literacy thanks to blogs and public educational campaigns
- DIHs reinforced their position being recognized hubs for train-the-trainers - host of BCT tests
- Infrastructures have been enhanced in rural areas and compared to current 40-45% (2025), 70% of rural farms have access to fast broadband

2030

- BCT-based tools and methodologies that automate reporting, certification, audits have been developed
- EU-wide BCT frameworks for certification, auditing, and inspection completed
- BCT-based microcredit, insurance, and financing tools have been designed and tests started with farmers, smallholders and other stakeholders

The suggestion to use **digital tools for real-time monitoring** is very challenging but also necessary, to reduce the fragmentation across funding mechanisms and guarantee synergies and efficiency.

This point requires a specific implementation plan as well:

- Phase 1 (Q1 2026) - Set up a **cross-DG taskforce** (AGRI, RTD, CNECT, ENV, JRC) to coordinate strategy, scope, and alignment with EU data initiatives; ask external experts/third-parties if there is a Platform to be used or only partially integrated (unique dashboard)
- Phase 2 (2026) - Launch a **topic** under Horizon Europe to design and test the platform with existing pilots (Technical Development & Piloting)
- Phase 3 (2027 onwards) - Roll out the monitoring system EU-wide

Specific channels to collect the farmers' feedback and experiences along the way need to be integrated into the monitoring framework as well.

9.4.5. Encouraging International collaboration

In an era of globalized trade and climate volatility, the European Union faces growing pressure to secure the integrity, resilience, and sustainability of its food supply chains. Food production, processing, and distribution are no longer confined within national borders. As an example, imports of raw materials and ingredients which are neither produced in the EU nor available in sufficient quantities, are needed to produce many value-added products.

A single agricultural product sold in a European supermarket may involve dozens of actors across multiple continents—farmers, processors, shipping companies, customs authorities, retailers, and regulatory bodies. This complexity not only increases the risk of contamination, fraud, and logistical disruption but also complicates efforts to ensure compliance with EU food safety, sustainability, and ethical sourcing standards.

In this context, **cross-border collaboration becomes an indispensable component of any strategy to reinforce the safety and resilience of global food supply systems.** Blockchain technology (BCT), when deployed effectively and internationally, offers a robust mechanism to address these systemic vulnerabilities. The full benefits of blockchain in food sup-

ply chains can only be realized through coordinated international action. A blockchain system limited to one region or one part of the supply chain fails to address the inherent cross-border nature of modern food networks. Interoperability between systems in different jurisdictions, standardisation of data protocols, mutual recognition of digital certifications, and shared governance mechanisms are essential. For example, a blockchain traceability solution for cocoa products originating in West Africa must be seamlessly integrated with the processing and certification systems used in Europe to verify child labour-free and deforestation-free sourcing. Similarly, perishable food imports from Latin America or Southeast Asia must be accompanied by real-time data on temperature control and handling conditions to ensure compliance with EU safety standards.

This degree of integration requires not only **technological alignment but also legal and institutional coordination**. International cooperation should extend to the development of harmonized standards for blockchain-enabled traceability, as well as mutual recognition of smart contracts, digital signatures, and regulatory reporting frameworks. Moreover, capacity building in developing countries is critical, enabling smaller producers to participate in digital traceability schemes and benefit from premium market access, rather than being excluded by the digital divide.

The European Commission has already taken important steps through initiatives like the European Blockchain Services Infrastructure (EBSI), which demonstrates how blockchain can support public services. However, these efforts must now be scaled and extended through partnerships with international organisations such as the FAO, WTO, ISO, and Codex Alimentarius, as well as through bilateral agree-

ments and digital trade arrangements with key food-exporting nations.

Mainstreaming blockchain-based traceability as a global public good will reinforce Europe's food sovereignty, strengthen consumer trust, and protect public health, while promoting fair trade and environmental stewardship. Without cross-border collaboration, Europe risks building digital silos in a supply chain that is intrinsically global. By acting as a convener and standard-setter, the EU can advance a vision of digitally empowered food systems that are safe, resilient, and trustable—not only within its borders, but across the entire value chain from production to consumption.

Europe stands at a pivotal juncture where technological innovation must align with geopolitical, economic, and environmental priorities. Among these innovations, Blockchain Technology (BCT) offers transformative potential.

To fully leverage this, Europe must not only scale domestic applications but also advocate for the international mainstreaming of BCT.

Advices:

1. **Strengthen European investment in blockchain diplomacy**, with DG AGRI, DG CONNECT, DG ENV, ENISA, and the EEAS playing a central role.
2. **Promote European blockchain standards** in trade negotiations, development aid, and digital cooperation frameworks.
3. Establish a **regulatory sandbox** for blockchain-based applications in agri-food trade, in coordination with EBSI (European Blockchain Services Infrastructure). Allow for experimentation with smart contracts, digital customs processes, and sustainability tracking under EC oversight.

6

Advices
identified

4. **Support international pilot projects** using blockchain in supply chains, ESG compliance, trade documentation automation and digital public services, involving all the supply chain actors, starting from farmers

5. **Advance interoperable solutions**, co-developed with global partners but anchored in European principles.

6. **Incentivize multinational companies** operating in Europe to adopt blockchain-enabled traceability and reporting.



Final acknowledgement

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