TITAN

Transparency solutions for transforming the food system

Deliverable 3.6 – Approaches for overcoming cross-cutting challenges

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Executive Summary

Digital technologies can support transparency in food supply chains, but their suitability cannot be assessed solely by technical capabilities. Transparency also depends on the information being made visible, its intended users and purposes, and the wider data, stakeholder, organisational and validation conditions through which it is produced and used. Building on earlier WP3 research, D3.6 presents the final Digital Transparency Approach for examining the suitability of technology as a context-dependent socio-technical question. The approach is applied to four TITAN SME technology-provider cases covering professional food-risk intelligence, lot-level agricultural transparency, product provenance and authenticity, and hospitality inventory and food-waste transparency. The case analyses examined transparency purposes, stakeholder relationships, material configurations, fit-for-purpose relationships, design choices, and significant reconfigurations.

Three main cross-case findings emerged. First, digital information needs to match its intended use and interpretive limits. Greater visibility or stronger technical verification does not automatically expand what the resulting transparency can reasonably support. Different forms of information and assurance have different interpretive limits. Second, consequential transparency conditions often extend beyond the focal technology to include data quality, stakeholder participation, validation, integration, organisational practices and physical deployment conditions. Third, transferability and scaling involve contextual adaptation rather than identical replication. This points to potential reuse of relatively stable technical or informational components, while consequential elements may require reconfiguration as product, organisational, data, regulatory or physical conditions change.

Evaluation with the participating SMEs supported retaining the approach's core analytical structure and informed the addition of five practical activities (namely, Frame, Examine, Connect, Diagnose, and Prioritise) to support application and the prioritisation of appropriate responses. D3.6 also translates the findings into practical recommendations for SMEs, investors, and policymakers and provides a case-derived contextual inventory of relevant digital technologies and methodologies in the Appendix, including their specific functions and implementation boundaries.

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Introduction

The European Green Deal is the central strategy of the European Union to transform European society with a modern, resource-efficient and competitive economy while addressing climate and environmental challenges. The Farm to Fork strategy follows the path traced by the European Green Deal while responding to increased public awareness and the growing demand for a Food System capable of providing healthy, sustainable and affordable food. All players in the Food Value Chain are called upon to contribute to this goal thanks to recent technologies and recent discoveries in the sector. Farm to Fork aims to set a global standard that can overturn the current paradigm consisting of air, water and soil pollution, loss of biodiversity, climate change, and excessive consumption of natural resources.

For such an agrifood system to flourish, consumers must have better access to healthy, sustainable and affordable food, with transparent information about the integrity and true value of food, so that they can make better food choices that are necessary to increase demand. Enhancing transparency is an essential element in achieving this goal. Without sufficiently credible, interpretable and verifiable information, sustainability claims run the risk of becoming hollow marketing phrases instead of useful information that all the actors in the value chain (producers, sellers, consumers) can use to make choices that align with their values.

TITAN intends to leverage transparency and digital innovations in the food sector to pursue this paradigm shift: transforming the food system into a demand-driven economy that provides consumers with healthy and sustainable food. To achieve this goal, TITAN will provide a broad platform for the development of pre-identified technologies and pilots that will be selected during the project through an open call for proposals, also by facilitating the involvement of primary and secondary stakeholders in this process, analysing current policy to set up a set of recommendations, and finally setting up an inventory to identify current digital innovations and future challenges.

As one of the work packages of TITAN, *WP3 – Digital technologies* aims to develop an approach that stakeholders can use to determine which technologies to apply to meet their requirements and overcome challenges in their context. Building on the groundwork laid in the previous publications of WP3 (D3.1 – Requirements and cross-cutting challenges for transparency and D3.4 – The first version of the approach for overcoming cross-cutting challenges), this document presents the final version of the approach, iteratively developed with contributions from selected TITAN SME technology providers.

Objectives of the document

The objectives of this document are to finalise and evaluate the digital transparency approach, which builds on the first version presented in D3.4. This deliverable aims to assess how the approach performs across different technology provider contexts and to identify the main conditions, limitations, and insights arising from those cases. It also aims to identify and contextualise technologies and methodologies arising from the four cases in relation to their transparency purposes and implementation contexts. Lastly, this document aims to translate the identified evidence into practical guidance for technology providers and other stakeholders involved in the design or adoption of digital transparency solutions.

Associated tasks

This deliverable report builds on the previous findings of WP3, and is linked to T3.1 – Requirements on digital technologies and methodologies for creating transparency in the food supply chain and associated cross-cutting technological challenges, T3.2 – Create an inventory of state-of-the-art technologies and methodologies for opening data and transparency, and T3.3 – Develop and evaluate approaches for overcoming cross-cutting challenges.

How to read this document

As this document presents the final version of the approach developed within WP3 and its evaluation, it contains connections to previous deliverable reports. To develop a more comprehensive understanding, it is also recommended to read D3.1 – Requirements and cross-cutting challenges for transparency, and D3.4 – The first version of the approach for overcoming cross-cutting challenges. The technologies and methodologies presented in this document are derived from case studies conducted with selected TITAN SME technology providers, who are involved in D4.5 – Final integrated pilot report for food safety, D5.5 – Final integrated pilot report for sustainability, and D6.5 – Final integrated pilot report for health. D3.6 provides a case-derived contextual inventory of relevant digital technologies and methodologies, and a broader inventory is provided in M3.7 – Technology scan review and D3.4 – The first version of the approach for overcoming cross-cutting challenges documents.

1. Background

In line with the growing demand for transparency, digital technologies are increasingly used in food supply chains (FSCs) to support traceability, food safety, regulatory compliance, risk management, operational efficiency, and consumer engagement. Technologies such as the Internet of Things (IoT), blockchain, artificial intelligence, digital platforms, and data analytics have improved the collection, processing, transfer, and interpretation of information at a greater scale and with greater efficiency (Astill et al., 2019). However, considering technical aspects alone is not enough to address the complexity of FSC transparency, which is characterised by specific food products, the scale of operations, regulatory environments, industry norms, and cultural differences, among other factors (Trienekens et al., 2012).

Today's long and global FSCs operate within complex stakeholder networks, where stakeholders often disagree over what should be disclosed, to whom, and under what conditions, and have different information needs, responsibilities, capabilities, incentives, and power (Kos & Kloppenburg, 2019). On the other hand, they depend on one another to generate, verify, and share information to achieve transparency. Digital technologies may transfer these interactions to digital environments, but the effectiveness of a transparency solution cannot be assessed solely through its technical functionality. Organisational processes, stakeholder participation, fit-for-purpose, asymmetries, and dependencies carry significant importance in digital transparency arrangements (Wognum et al., 2011). At the same time, digital technologies should not be perceived as neutral channels for creating transparency (Donaldson, 2022), as design choices regarding data models, algorithms, validation procedures, interfaces, and access permissions can affect the type of transparency a solution provides and the conclusions users can draw from it.

Finally, digital transparency arrangements rarely remain static. Regulations, contractual requirements, industry standards, certification schemes, organisational priorities, user needs, and technical possibilities change over time, altering how digital transparency is configured in a given context. As a result, digital transparency configurations may need to be adapted as they move between products, organisations or supply-chain contexts. Taken together, these considerations call for a context-dependent and socio-technical approach to digital transparency (Zorer et al., 2024).

2. Methodology

This chapter describes the development of the context-sensitive approach for analysing digital transparency in FSCs and significant decisions made in the process. The methodology reflects different research stages and combines empirical evidence from stakeholder interviews and TITAN SME technology provider case studies. The approach itself is presented in **Chapter 3**.

2.1. Development of the Digital Transparency Approach

The first version of the approach introduced in D3.4 centred on the connections between requirements, cross-cutting challenges, and potentially suitable digital technologies for transparency in a given context. Grounded in the FSC transparency literature, D3.4 concluded that the suitability of digital technologies for transparency creation cannot be assessed independently of the stakeholders, requirements, and challenges involved in the process. Building on this perspective, the approach was further developed through continued empirical research throughout the project. The findings provided insights into how stakeholder relationships, transparency requirements and challenges, digital technologies, and other conditions for transparency creation vary across different contexts. Through an iterative design process, these insights were incorporated into a structured approach presented in this report.

In addition to requirements, challenges, and technology-fit considerations, the new version of the approach expands to consider the purpose of transparency, asymmetries and interdependencies within stakeholder networks, the technical and organisational configuration of digital transparency over time, the limitations of such configurations, and adaptation needs to sustain digital transparency as conditions change. After the provisional structure of the approach was established, it was applied to four selected TITAN SME technology providers. Accordingly, the final approach supports decisions about technology suitability and configuration by examining whether particular technologies, together with the wider socio-technical arrangement in which they operate, are fit for a defined transparency purpose and what contextual conditions or adaptations are required.

2.2. Case Selection and Data Sources

The broader empirical insights highlighted the important role technology providers play in shaping transparency configurations through their design decisions concerning data, system architecture, validation, and access. Furthermore, they hold a central position in the stakeholder networks of their context and can provide insights into different perspectives through their interactions with other stakeholders (Otter & Robinson, 2024). In this relation, four TITAN SME technology providers were

selected for detailed analysis: Agroknow, Agricolus, QualityChain and TotalCtrl. The cases were selected based on the variations in transparency purposes, relevant food products and sectors, operational scope across countries, stakeholders involved, digital technologies, and governance structures. This enabled analysing the approach across substantially different digital transparency configurations.

The development and application of the approach drew on several data sources throughout the project. Broader empirical development was informed by 27 semi-structured interviews with TITAN SMEs and external stakeholders across European food networks, while the detailed SME case applications drew on ongoing interactions with selected TITAN SME beneficiaries, pilot activities, and project progress reports from TITAN pilots (WP4, WP5, and WP6). Additional interviews with selected TITAN SME technology providers provided necessary input to clarify unresolved issues and verify key interpretations and outcomes. To maintain scientific rigour, the data sources and conclusions made were kept distinguished as documented evidence, information reported by project partners, and researcher interpretations throughout the analysis, evaluation, and refinement processes.

2.3. Case and Cross-Case Analysis

After the provisional structure of the approach was established, a common analytical discipline was applied to all four cases. For each case, the analysis identified the focal transparency purpose and scope, stakeholder dynamics, requirements and challenges, the main technical and organisational configuration, and important conditions, limitations, and changes affecting the transparency arrangement. The preliminary analysis results were organised in standardised templates within Microsoft Excel to support comparison while retaining the specific characteristics of each case and its context. Case-specific analytical threads were then consolidated around central transparency relationships where several analytical lenses intersected, while retaining coverage of materially different transparency purposes or functions within the focal arrangement.

The findings of preliminary case analyses were then reviewed with the respective SMEs. This stage served two related purposes: 1) to clarify or verify the empirical description of each case and 2) to evaluate the credibility, usefulness, and perceived practical applicability of the approach from a technology provider perspective. The same substantive version of the approach was maintained across all four SME evaluations to support consistent comparison of the feedback. Factual corrections to individual case applications were incorporated, while recommended changes to the approach itself were deferred until the evaluation stage was complete in all cases. Following the individual analysis and revision of each case, a cross-case analysis was conducted to identify recurring findings and key differences among digital transparency configurations. Accordingly, the emerging interpretations

were examined in relation to contrasting evidence and context-specific conditions. The insights from SME evaluations were synthesised and considered in finalising the approach and its practical application. The case findings and cross-case analysis are presented in **Chapter 4**, while the evaluation results and finalisation of the approach are presented in **Chapter 5**.

2.4. Limitations

While the four SME cases were selected to provide some variety in digital transparency configurations, this study does not intend to cover all possible digital technologies or to statistically represent the wider population of digital technology providers or FSCs across Europe. Although the preliminary development of the approach drew on stakeholder interviews across heterogeneous European food networks, the detailed case analyses and evaluation of the approach are primarily technology-provider-centred. As a result, the perspectives provided on behalf of other stakeholders are drawn from technology providers' interpretations and narratives and were not systematically re-evaluated in each case. Additionally, the evaluation of the approach itself is limited to SMEs assessing how the researchers applied it in their cases, rather than implementing it themselves and evaluating it based on their own experience. Therefore, the evaluation provides evidence on the perceived credibility, usefulness, and practical applicability of the researcher-applied approach. Lastly, the cross-case analysis provided in this document should be interpreted as context-sensitive analytical and practical insight and not as generalisable conclusions for the broader European food networks.

3. Digital Transparency Approach

The approach presented in this report treats digital transparency as a context-dependent arrangement that brings together social, technical, and organisational elements. It provides a structured way to analyse a specific digital transparency arrangement, with particular attention to its purpose and scope; the stakeholders involved and their relationships; the design choices that shape the technical and organisational configurations; and how those configurations change over time. In doing so, the approach supports a fit-for-purpose analysis and helps identify the main dependencies, limitations, and trade-offs that shape how the arrangement works in practice.

To address the complexity of digital transparency creation in FSCs, the approach establishes a bounded focal digital transparency arrangement as the common object of analysis and examines it through several interconnected analytical lenses. Each lens foregrounds a different aspect of the arrangement, and these lenses do not represent separate or sequential stages. Stakeholder relationships may shape data requirements and access conditions; technology design choices may redistribute responsibilities or create new dependencies; validation mechanisms may affect whether

particular information is adequate for its intended use; and changes in regulations, market dynamics, or technical capabilities may require parts of the arrangement to be adapted or reconfigured. These relationships are central to the approach, and the insights from one analytical lens may change how different aspects of the same arrangement are understood through other analytical lenses.

Finally, the approach is intended as an analytical and diagnostic tool for stakeholders involved in the design, implementation, or review of digital transparency arrangements. It should not be interpreted as a means of creating a universal transparency score, ranking digital technologies, or maximising disclosure (Mol, 2015). Its purpose is to provide a consistent structure for examining how a particular digital transparency arrangement is configured, whether it is fit for its intended use, where important dependencies, boundaries or unresolved issues remain, and where technical or organisational changes may be warranted.

3.1. The Focal Digital Transparency Arrangement

Digital technologies may support multiple purposes, organisational functions, users, and information flows simultaneously. For this reason, analysing an entire technology, platform, or company without defining the relevant transparency arrangement can make it difficult to determine which requirements, dependencies, or limitations are relevant to the analysis. The approach addresses this by establishing a bounded focal arrangement around a particular transparency purpose, object, intended use, and relevant stakeholders.

The focal digital transparency arrangement specifies what information is made visible, to whom, for what purpose, and through which outputs or interactions. Where relevant, related sub-configurations may be distinguished when they support different transparency functions or operate under different conditions. The boundaries of the focal arrangement are not assumed to be fixed. Rather, they provide an analytical reference point for examining how the arrangement functions in its current context. As stakeholder relationships, material configurations, fit-for-purpose conditions, and reconfigurations are examined, the analysis may reveal consequential information prompting reconsideration of the initial boundaries of the focal arrangement.

3.2. Stakeholder Relationships, Requirements, Challenges, and Tensions

This analytical lens examines the stakeholders involved in the focal digital transparency arrangement, their relationships, and the requirements, challenges, and tensions associated with the arrangement. Relevant stakeholders may include those who produce or control information, configure the arrangement, use or act on its outputs, are represented or affected by the information, or shape the

conditions under which the focal arrangement operates. The analysis considers stakeholders' roles, responsibilities, capabilities, and limitations, as well as key interdependencies, asymmetries, and tensions between them. Requirements may arise from regulatory obligations, contractual relationships, industry norms, organisational objectives, or specific user needs, and may align, differ or conflict across stakeholders.

Challenges are examined in relation to these stakeholder relationships and requirements rather than being treated only as technical barriers. They may concern, for example, data availability and access, participation and capacity, allocation of responsibilities, validation, or organisational workload. This analytical lens is also connected to material configurations, reconfigurations, and fit-for-purpose analysis. Stakeholder relationships, requirements, challenges, and tensions can shape choices about data, access, validation, and technology, while those choices can redistribute visibility, control, responsibilities, and dependencies. These interactions can affect whether the transparency arrangement remains fit for its intended users and purposes as it is reconfigured.

3.3. Material Configurations

This analytical lens examines how information is collected, processed, represented, accessed, validated, and used within the focal digital transparency arrangement. This may involve data capture mechanisms, data structures and processing methods, digital technologies, system integrations, interfaces and outputs, access conditions, validation processes, and relevant human or organisational practices. Beyond analysing which technical and organisational components are present, it focuses on how they are configured together and how they shape the forms of visibility, interpretation, and use that the focal digital transparency arrangement can provide.

Material configurations of a transparency arrangement cannot be examined independently of the other analytical lenses. How data, digital technologies, access control, or validation mechanisms are configured is intertwined with the transparency purpose, stakeholder roles, responsibilities, and capabilities, their relationships, and relevant requirements and challenges. Examining these configurations may reveal dependencies and limitations that are less visible when technical components are considered in isolation. Similarly, insights from other analytical lenses may alter how the material configuration of the same arrangement is understood.

3.4. Fit-for-Purpose Analysis

This analytical lens examines different fit-for-purpose relationships within the same focal digital transparency arrangement. Whether a particular configuration of information, evidence, practices,

and digital technologies is sufficient for a particular stakeholder, purpose and use depends on the conditions (Behnke & Janssen, 2020). These conditions may include explicit thresholds alongside qualitative and context-dependent judgements of adequacy. What is considered fit-for-purpose may change as requirements and uses evolve, regulatory conditions change, material configurations are adapted, or market dynamics shift. Therefore, this analytical lens pays particular attention to the boundaries of these fit-for-purpose relationships in terms of what the configuration can reasonably support, what conditions this depends on, and what remains uncertain, unavailable, or outside the relevant scope.

3.5. Reconfigurations

This analytical lens examines how the focal digital transparency arrangement takes shape and changes over time through significant design choices, adaptations, and changing contextual conditions. Reconfigurations may involve technical components, data and information structures, organisational practices, stakeholder participation, or the relationships and dependencies through which the transparency arrangement operates. They may emerge as purposes and requirements evolve, new users or contexts become relevant, technical possibilities develop, or experience with the existing configuration reveals new needs, tensions, or limitations. Reconfiguration does not necessarily indicate that the previous configuration was deficient. Examining these dynamics helps identify the conditions that shape the current configuration and its capacity to accommodate future changes, including implications of changes for benefits, trade-offs, and fit-for-purpose relationships.

3.6. Findings, Interpretations, and Suggestions

Insights across the analytical lenses are brought together in the case analyses to develop findings and interpretations concerning the focal digital transparency arrangement. These may identify significant strengths, dependencies, limitations, tensions, boundaries, or conditions that affect how the arrangement operates in its context. Some findings concern documented characteristics of the arrangement, while analytical interpretation helps examine the implications of those characteristics for the purposes, stakeholders, configurations, and fit-for-purpose relationships under consideration. The same analysis may inform suggestions for adapting or reconfiguring aspects of the arrangement. Such suggestions are grounded in the specific conditions identified in each case and are considered alongside their expected benefits, trade-offs, implementation requirements, and potential new dependencies. In this sense, they represent context-dependent suggestions rather than generally applicable solutions, and they provide the basis for evaluating the approach with the participating TITAN SMEs.

4. TITAN SME Case Application of the Approach

The cases cover different transparency purposes, stakeholder settings, material configurations, and points of application within FSCs. Agroknow case concerns professional food-risk intelligence; Agricolus case focuses on lot-level production, sustainability, and farmer contribution; QualityChain case addresses product provenance and protected product/lot identity; and TotalCtrl case concerns hospitality inventory, procurement, food-waste measurement, and reporting. This variation enables examining how digital transparency arrangements are configured and used under different conditions.

Focal digital transparency arrangement	Main transparency objectives	Central analytical threads
Agroknow professional food-risk intelligence arrangement	Supplier-related food-safety risk visibility and interpretation for prioritisation and review; emerging ingredient-hazard-origin risk intelligence for preventive testing, review, and planning; usable risk intelligence within different professional and enterprise workflows without losing relevant context.	Supplier-risk representation and prioritisation; Predictive ingredient-risk sufficiency; Contextual use and reconfiguration.
Agricolus production lot transparency arrangement	Lot-level production history and provenance for traceability and product/quality assurance; sustainability practices and performance for downstream communication and trust; visibility of farming work, particularly operation duration, to support understanding of producer contribution.	From farm data to trustworthy lot-level transparency; Public sustainability disclosure, selection, and interpretation; Making farmer contributions visible.
QualityChain product-provenance and authenticity transparency arrangement	Visible and tamper-evident product-lot provenance; verification of a protected product/lot-linked identity to support anti-counterfeit authentication; affordable, usable, and adaptable deployment for small agri-food producers.	From tamper-evident records to sufficient provenance; Low-friction SME and consumer transparency; Protected-code verification under real-world conditions.
TotalCtrl automation-enabled hospitality inventory and food-waste transparency arrangement	Current inventory and expiry-related status, together with purchasing and supplier information, for operational control; measurable and actionable food-waste information for prevention and improvement; structured and configurable information for management and ESG/compliance reporting.	Maintaining digitally continuous inventory visibility; Low-burden automation with resilient data production; From visibility to operational action and reporting.

Table 1. The overview of selected SME cases

Each case application establishes a focal digital transparency arrangement, with relevant sub-configurations, variants, or enabling components distinguished where necessary. The analytical lenses introduced in **Chapter 3** are considered together within each arrangement. The results are organised around case-specific analytical threads that bring together the focal purpose and scope; stakeholder roles, responsibilities, and relationships; relevant requirements, challenges, and tensions; material configurations; fit-for-purpose relationships; and reconfigurations. Because these analytical lenses are interconnected, the same empirical condition may be relevant to more than one aspect within a thread. The analytical threads do not constitute additional analytical lenses. Instead, they provide a structure for presenting how the different analytical lenses intersect around the central issues identified within each case.

Each case section introduces the focal arrangement and its analytical focus, followed by the analysis organised around the central analytical threads. Suggestions for technical or organisational changes are presented where the analysis identifies opportunities to strengthen particular fit-for-purpose relationships, address consequential limitations or dependencies, or adapt the arrangement to relevant contexts. These suggestions are considered in relation to their potential benefits, trade-offs, implementation conditions, and possible new dependencies. The chapter concludes with a cross-case analysis of the findings emerging across the four digital transparency arrangements.

4.1. Agroknow Case

The Agroknow case focuses on a **professional food-risk intelligence arrangement**, through which primarily external food-safety information is collected, structured, and analysed to make supplier- and ingredient-related risks visible to professional food-company users. The arrangement supports supplier risk prioritisation, preventive action, and supplier and ingredient management within defined professional food safety contexts.

Two principal sub-configurations form the focal arrangement: **Supplier-risk intelligence** represents supplier-, location- and parent-related food-safety histories and risk through profiles, incidents, severity indicators, scores or alerts, and supporting records. **Ingredient-risk forecasting** represents historical and expected risk through ingredient–hazard–origin configurations. **Enterprise integration** provides an enabling layer through which risk intelligence can be embedded in existing supplier and quality management workflows, as demonstrated through the implemented API-based proof of concept with an enterprise quality-management platform.

Element	Description
Transparency purpose and objects	Professional visibility and interpretation of supplier-related food-safety risk and ingredient-hazard-origin risk for supplier review, preventive action, testing, sourcing, and planning.
Intended uses	Supplier screening and prioritisation; investigation and sourcing attention; early warning and targeted testing; sourcing and regulatory review; preventive planning; use of supplier-risk and predictive-ingredient risk intelligence across professional and enterprise workflows.
Main actors and roles	**Agroknow** selects and structures source information and configures modelling, scoring, dashboards and integration mechanisms. **Pilot professional users** apply supplier-risk and predictive information across several professional functions. **Assessed suppliers** are represented through supplier-risk information and may be affected by subsequent buyer actions. **External food-company evaluators** provide requirements and assessments concerning scalability, contextual relevance, and workflow fit. **External data/source organisations** influence what evidence becomes available and attributable. **Enterprise-integration actors** configure the transfer of risk intelligence into organisational workflows.
Information made visible	Supplier/location/parent-related incident histories and risk scores and severity indicators; ingredient–hazard–origin historical and predicted patterns; model performance and explanatory information; detailed supporting records and evidence.
Principal sub-configurations	Supplier-risk intelligence; ingredient-risk forecasting.
Enabling configuration	Enterprise integration, including data/schema mapping and an implemented API-based proof of concept with an enterprise quality-management platform.
Outputs and access	Supplier profiles, scores, and alerts; historical and predictive dashboards; filters, performance, and explanatory information; drill-down to supporting records; risk information embedded in enterprise supplier or quality records.
Scope boundaries	The case does not assess Agroknow's complete commercial portfolio, claim complete global source coverage, independently establish statistical validity beyond the documented methodology, determine the legal compliance of client decisions, establish whether every supplier score is objectively fair, assess the complete cybersecurity architecture, or address consumer-facing transparency. The analysis of enterprise integration is limited to the documented implementation and does not infer routine deployment beyond that evidence.

Table 2. Overview of the focal digital transparency arrangement of the Agroknow case

The case analysis centres on three interconnected threads: **supplier-risk representation and prioritisation**, **predictive ingredient-risk sufficiency**, and **contextual use and reconfiguration**. The tables make visible how the analytical lenses become relevant within each thread. The accompanying analysis focuses on the relationships among these aspects, and the table rows do not represent separate components or stages of the transparency arrangement.

4.1.1. Supplier-risk representation and prioritisation

Analytical aspect	Application within the analytical thread
Focal purpose and object	Supplier/location/parent-related food-safety risk made visible for professional supplier screening, prioritisation, scrutiny, and possible sourcing attention.
Stakeholders and relationships	**Agroknow** holds substantial configurational influence over source structuring, classification, supplier representation, scoring, and interface design. **Professional users** interpret the resulting information and can translate it into investigation, testing, audit, supplier engagement, specification or procurement action. **Assessed suppliers** may experience consequences from these decisions, while direct evidence of their interpretation or influence over the representation remains limited. The risk-intelligence arrangement also depends on **external source organisations** whose publication and access practices affect what supplier-related evidence becomes available.
Requirements	Risk information should draw on sufficiently attributable, relevant, and validated evidence and retain a connection to supporting records. Supplier-level representations should support scalable prioritisation while preserving sufficient context concerning entity relationships, evidence coverage, and data availability. Professional users also require enough explanation and underlying detail to interpret aggregated representations appropriately.
Challenges	Relevant external information remains fragmented across sources, languages and formats. The volume of supplier-related information can exceed the capacity of professional attention. Inspection intensity, publication practices, identifiers, and incident histories also vary across suppliers, affecting the amount of attributable evidence available for representation.
Tensions	Stronger attribution and evidentiary traceability can narrow the evidence universe and increase dependence on formal publication systems. Aggregation and prioritisation reduce the monitoring burden but increase dependence on entity resolution, scoring, and evidence coverage choices. Scalable supplier comparison also coexists with uneven supplier observability and the professional need for contextual inspection.

Material configurations	External incident and recall information is selected, aggregated, cleaned, and normalised, with cross-referencing to support source and data validation. NLP, ontologies and structured categories support further processing and representation. Supplier information is organised at the supplier-location and parent levels and linked to incidents, severity indicators, and risk scores. Scores, alerts, and prioritised views are combined with filters, explanations, and access to supporting details. Historical evidence also describes user visibility into evidence considered and aspects of the weighted risk calculation.
Fit-for-purpose relationships	Supplier-risk information can be sufficient to prioritise attention, investigation, engagement, and possible procurement review. It does not by itself establish supplier non-compliance. Interpretation also depends on what supplier-related evidence can be observed and attributed. The case evidence establishes no general organisational threshold through which a particular supplier score automatically determines a particular action.
Reconfigurations	The risk-intelligence arrangement has transformed fragmented external food-safety records into structured professional risk intelligence and configured large supplier-information volumes through scores, alerts and prioritised views. Layered access to supporting evidence has been retained alongside aggregation. Important design choices include prioritising structured and attributable evidence, configuring supplier-level aggregation, and maintaining inspectability through layered disclosure.

Table 3. Supplier-risk representation and prioritisation

Interconnections within the thread

Supplier-risk representation brings together the availability and quality of external evidence, professional attention constraints, Agroknow's configurational choices, and the decision capacity of client organisations. Structured and attributable sources strengthen the credibility and traceability of the representation, while also bounding what can become visible when relevant information remains unavailable, is poorly attributable, or falls outside formal publication systems. Aggregation and scoring address another condition of professional use: large supplier populations cannot be monitored through continuous manual inspection of individual records. In this regard, the resulting supplier representation reflects both the evidentiary environment and design choices concerning source validation, entity representation, aggregation, and prioritisation. A reported supplier-risk episode illustrates how these relationships can influence practice, where supplier-linked risk information prompted additional investigation and professional follow-up. This demonstrates how supplier-risk intelligence can support scrutiny and professional action without establishing a general decision rule that would automatically determine the resulting action based on a particular score or representation.

These relationships also demonstrate important asymmetries. Agroknow configures the representation, professional buyers and food-safety actors can act on it, and assessed suppliers can

experience consequences from those actions. Layered access to supporting evidence helps professional users move between prioritised representations and more detailed inspection. Nevertheless, supplier observability remains consequential. Differences in inspection intensity, publication, identifier quality, and attributable incident histories may affect how much digital evidence accumulates around different suppliers. The available evidence does not establish systematic bias in supplier-risk scoring. The issue nevertheless places an interpretive boundary around supplier comparisons: the representation can support scrutiny and prioritisation without constituting direct proof of supplier non-compliance.

4.1.2. Predictive ingredient-risk sufficiency

Analytical aspect	Application within the analytical thread
Focal purpose and object	Ingredient-hazard-origin risk and expected future incident patterns made visible to support preventive testing, review, sourcing, and planning.
Stakeholders and relationships	**Agroknow** configures the predictive models, data selection and validation mechanisms. **Professional users** employ supplier and predictive risk intelligence across different QA/QC, procurement, regulatory, and NPD responsibilities. **External data organisations** influence the availability of relevant predictive inputs, while **laboratory testing, certification, audit, and related professional controls** provide forms of verification distinct from predictive risk intelligence.
Requirements	Predictive configurations require adequate historical information and appropriate model selection and validation procedures. Professional users require sufficient performance, uncertainty or confidence information, explanation, and underlying evidence to interpret outputs. Configurations also need to accommodate materially different commodities, hazards, origins, and relevant regulatory contexts.
Challenges	Relevant data and risk drivers are not equally available across commodities and origins. Different risk objects can therefore depend on materially different evidentiary configurations. Extending predictive capabilities across heterogeneous settings requires continued attention to data availability, validation, and applicability.
Tensions	Formal model/data criteria support methodological credibility and comparability, while commodity-specific conditions can require adaptation. Extending predictive coverage can therefore involve different evidentiary configurations even when the broad forecasting capability remains similar.
Material configurations	Forecasts use ingredient-hazard-origin configurations and time-series representations. Predictive inputs combine multiple external risk-driver data where available, and the documented methodology applies explicit data-eligibility and time-series validation procedures. Dashboards provide historical and forecast views,

	performance information, explanatory risk drivers and supporting detail. Commodity-specific configurations can use different combinations of risk-driver information depending on data availability.
Fit-for-purpose relationships	Predictive information can be sufficient to direct preventive attention, testing, sourcing review, and planning without establishing the condition of a specific batch. At the model-development level, explicit data-eligibility and validation criteria form part of the evidentiary basis for assessing predictive applicability across different commodity configurations.
Reconfigurations	Agroknow developed and refined multi-factor forecasting, formal ingredient/data selection, validation, and explanatory predictive interfaces. Expansion to honey involved adaptation to different data availability and risk-driver conditions. Extensions to other commodities, hazards, or regulatory contexts can similarly require changes to data, validation, and interpretation.

Table 4. Predictive ingredient-risk sufficiency

Interconnections within the thread

Predictive risk intelligence depends on the relationship among the available evidence, modelling and validation choices, the information exposed to users, and the professional purposes for which the forecast becomes relevant. The documented methodology provides explicit data-eligibility criteria, validation procedures, and performance measures for assessing predictive applicability, while dashboard functions allow users to inspect historical patterns, performance, and explanatory risk drivers. These mechanisms strengthen the credibility and interpretability of predictive outputs, but they do not prescribe one organisational response. Supplier and predictive information enter different professional functions within the pilot, while external company evaluations emphasise different concerns around scalability, commodity relevance, and workflow fit.

The distinction between predictive intelligence and direct verification provides an important fit-for-purpose boundary. In the case evidence, risk information prompted targeted laboratory verification, and the laboratory test established the condition of the relevant batch. In this sense, risk intelligence supported attention and verification without substituting for direct evidence. Commodity-specific configurations provide another dimension of the same analytical relationship. The honey configuration uses a different combination of available risk-driver information than the herbs-and-spices configuration. This adaptation does not, by itself, indicate deficient prediction. It shows that predictive sufficiency can depend on materially different evidentiary configurations. The predictive configuration also reflects a broader shift from primarily historical incident visibility to forward-

looking, multi-factor risk intelligence, making data eligibility, validation, and explanation more consequential for fit-for-purpose.

4.1.3. Contextual use and reconfiguration

Analytical aspect	Application within the analytical thread
Focal purpose and object	Supplier-risk and predictive risk intelligence are used across different professional functions and, where relevant, embedded within client-specific enterprise workflows, while retaining sufficient context for their intended use.
Stakeholders and relationships	**Agroknow** and **client organisations** depend on one another for contextual information, evolving needs and workflow semantics. **Pilot users** apply this risk intelligence across different professional responsibilities. **External food company evaluations** provide information on scalability, commodity relevance, and workflow fit. **Enterprise integration** involves Agroknow, client-side actors and external platform providers. Where non-public information enters the configuration, data ownership, access, and confidentiality relationships also become consequential.
Requirements	Outputs should remain adaptable across commodities, hazards, origins, and relevant regulatory settings. Enterprise integration should preserve sufficient provenance, meaning, and currentness when information moves between systems. Where customer-specific supplier information or risk factors are incorporated, their access, use, and disclosure should remain appropriately bounded to the relevant customer environment.
Challenges	Clients differ in professional functions, terminology, data structures, enterprise systems, and regulatory settings. Client data can require semantic clarification, cleaning, curation, and mapping. Extending configurations to new commodities or organisational settings may require new data, validation, and interpretation.
Tensions	Technical scalability coexists with contextual tailoring. Greater contextual information can improve professional relevance while increasing confidentiality, security, liability, and commercial considerations. API-based integration can reduce manual mediation while leaving dependencies around terminology, schemas, provenance, currentness, and organisational responsibility.
Material configurations	The pilot use spans supplier and tailored-prediction information across several professional functions. Historical enterprise integration could require client-specific data preparation and semantic mapping before information is aligned across systems. The implemented proof of concept reconfigures part of this pathway through REST API retrieval and schema transformation, embedding risk-intelligence outputs into enterprise records while retaining links to the underlying detailed records and contextual information. Food manufacturer-specific supplier information and customer-defined risk factors may also be incorporated into supplier-risk configurations under controlled access conditions, with access restricted to the

	respective customer environment. These customer-specific inputs remain distinct from the primarily public-data foundation of supplier-risk intelligence.
Fit-for-purpose relationships	Enterprise embedding changes the conditions under which supplier-risk and predictive information remain fit for their intended professional uses. Relevant meaning, provenance, currentness, and access become consequential when outputs move into client workflows, while contextual usability depends on the professional function and enterprise setting in which the information is encountered.
Reconfigurations	Configurations have been adapted to client needs, professional functions, commodity/data conditions, and enterprise workflows. The implemented enterprise-integration proof of concept demonstrates API-based embedding, while repeatability across heterogeneous enterprise schemas, update requirements, and governance arrangements has not been demonstrated. New commodities and regulatory contexts may similarly require context-specific adaptation rather than replication of an existing configuration.

Table 5. Contextual use and reconfiguration

Interconnections within the thread

Contextual use shows how the same technological capabilities become configured within different professional and organisational settings. Agroknow receives information about client needs, monitored ingredients, hazards, suppliers, and workflow conditions, while client organisations receive risk intelligence configured for particular uses. This reciprocal dependency shapes what becomes relevant, how outputs are interpreted, and which forms of integration are useful. Pilot evidence demonstrates cross-functional use within the pilot, while evaluations involving other food companies provide additional evidence concerning requirements and workflow fit without implying equivalent routine deployment across all organisations.

Enterprise integration makes these relationships particularly visible. Historical enterprise integration could require substantial client-specific data preparation and semantic alignment before information is usable across systems. The implemented proof of concept reconfigures part of that pathway through API retrieval and schema transformation. Technical connectivity, however, leaves dependencies concerning terminology, identifiers, provenance, update requirements, and client-specific configuration. Therefore, the proof of concept demonstrates integration capability without establishing a universally repeatable enterprise integration configuration. Non-public information creates a related governance boundary. Customer-specific information creates a related governance boundary. Where such information enters the arrangement, it operates under bounded access conditions within the relevant customer environment. These conditions can strengthen the contextual

relevance of risk intelligence while simultaneously introducing access, confidentiality, security, and commercial dependencies.

4.1.4. Findings and suggestions

Finding	Implication
Layered inspectability represents an existing strength. The risk-intelligence arrangement combines prioritisation with explanations, performance information, and access to supporting detail instead of relying solely on scores or forecasts.	Scaling or enterprise integration should preserve the relationship between operationally manageable representations and access to their evidentiary basis. Generic explainability should not be treated as an absent capability.
Supplier-risk representation remains conditional on observability. Aggregation across entities, products, and time operates within an evidence environment in which inspection, publication, and attribution can vary across suppliers. These differences can affect the amount and comparability of attributable evidence available for supplier-level representation.	Supplier-risk representations can support prioritisation, while interpretation needs to remain sensitive to what underlying evidence permits users to conclude. The evidence does not establish systematic scoring bias.
Predictive sufficiency becomes context-dependent when evidentiary configurations differ across commodities.	Users may need to understand the conditions of applicability for the particular commodity/model configuration, in addition to its output performance. Different input configurations do not, by themselves, indicate inadequate forecasts.
Contextual adaptation represents a demonstrated socio-technical strength. Agroknow configurations respond to client needs, professional functions, commodity/data conditions, and enterprise workflows.	Scaling concerns the meaning and use of risk intelligence alongside technical extensibility. New contexts may require changes to data, validation, interpretation or integration arrangements.
Where non-public information is included, its use is selectively bounded by access and contractual conditions.	Client-specific information can increase contextual relevance while introducing confidentiality, liability, security, and commercial conditions that remain consequential to how the arrangement is configured and used.

Table 6. Main findings from the Agroknow case

Suggestion	Intended contribution	Conditions and trade-offs
Preserve existing explainability and supporting-evidence capabilities, while reviewing whether contextual inspection remains sufficient as supplier-risk representations and integrations evolve.	Preserve scalable supplier-level prioritisation while helping professional users interpret entity relationships, evidence coverage, attribution, and supporting records.	Depends on current scoring, entity resolution, and contextualisation practices, some of which may already address the issue. Additional contextual detail can increase interface complexity and cognitive burden.
Where needed, make the evidentiary and applicability conditions of materially different predictive configurations concise and visible.	Support defensible interpretation when commodities cannot rely on identical combinations of risk-driver information and model conditions.	Should extend existing performance and explanation functions without duplicating technical information already available to users. Additional metadata may increase information load.
Preserve and, where useful, make the alignment between risk-intelligence outputs, supporting evidence, intended professional use, and workflow integration explicit as the arrangement evolves.	Support onboarding, cross-functional adoption, and future enterprise embedding while preserving appropriate reliance on and access to the underlying evidence.	The approach needs input from clients and professionals and should remain adaptable to different workflows, terminology, schemas, access conditions, and responsibilities. Existing customer success or integration practices may already fulfil some or all of this function, and additional templates could create unnecessary implementation burden.

Table 7. Main suggestions for the Agroknow case

The Agroknow case shows how professional food-risk transparency depends on the configuration of evidence, representations, validation mechanisms, professional uses, and organisational contexts in which risk intelligence is interpreted and acted upon. The risk-intelligence arrangement provides substantial capabilities for aggregating, prioritising, explaining, and adapting food-safety information, while the meaning and appropriate use of its outputs remain connected to the availability of evidence, commodity-specific data conditions, professional responsibilities, and the contexts in which the information is embedded. Consequently, the case highlights both the value of configurable risk intelligence and the importance of maintaining clear boundaries around what different supplier-risk and predictive representations can support as the arrangement evolves across users and settings.

4.2. Agricolus Case

The Agricolus case focuses on the **Production Lot transparency arrangement**, through which participating farmers and agronomists record and structure crop-production information that

Agricolus connects to a harvested production lot. The arrangement brings together production history and provenance, sustainability information, crop-specific quality, certification and transport attributes, and information concerning farming effort. Selected lot-level information becomes publicly accessible via a QR landing page.

The focal arrangement begins with farm-level data production and extends to lot-level visibility outside the farm. In this sense, it draws on parts of the wider Agricolus decision-support system where these contribute to the Production Lot, while excluding other precision-agriculture functions that do not directly contribute to the focal transparency purposes. **Tomato** and **rice** represent crop variants within the same Production Lot architecture. **Agriplug**, together with manual fallback, provides an enabling component for capturing operation duration rather than constituting a separate transparency arrangement.

Element	Description
Transparency purpose and objects	Lot-level production history and provenance; sustainability practices and performance associated with production; crop-specific quality, certification and transport attributes; farming effort represented through operation duration.
Intended uses	Product traceability and product/quality assurance; sustainability communication and interpretation; making farming work and producer contribution more visible in downstream interactions.
Main actors and roles	**Farmers** generate much of the underlying farm information, and their production practices, sustainability performance, and work are represented through the arrangement. **Independent agronomists** contribute professional expertise, co-design and support to farmers. **Agricolus, including Agricolus agronomists**, configures data structures, categories, calculations, interfaces, and disclosure arrangements and provides data-quality support. **Buyers, processors, and other downstream professionals** are the intended users of production, quality, certification, and sustainability information. **Consumers** form part of the public QR audience, although they have a more limited role in configuring the arrangement. **INRAE** contributes to the methodology and assessment of sustainability indicators.
Information made visible	Producer and field information; crop operations and inputs; harvested quantity and lot identity; sustainability indicators; crop-specific quality, certification and transport information; operation duration and total working hours.
Crop variants	Tomato and rice, using a common Production Lot architecture with crop-specific information structures.

Enabling component	AgriPlug-based automatic operation-duration capture with manual duration fallback where automatic capture is disrupted.
Outputs and access	Internal Production Lot record and a publicly accessible QR landing page containing selected lot-level information; incomplete sections are not rendered.
Scope boundaries	The analysis does not cover the complete Agricolus DSS or all precision-agriculture and forecasting functions, establish full GDPR/legal compliance, or assume that every potential crop configuration has been validated. It does not attribute environmental-performance improvements causally to the transparency arrangement, establish actual changes in buyer purchasing behaviour or farmer bargaining outcomes, or treat project labels such as "validated" or "commercially ready" as stronger evidence than the underlying implementation and evaluation support.

Table 8. Overview of the focal digital transparency arrangement of the Agricolus case

The case analysis centres on three interconnected threads: **from farm data to trustworthy lot-level transparency**; **public sustainability disclosure, selection, and interpretation**; and **making farmer contribution visible**. The accompanying analysis examines their relationships and interdependencies, and the table rows do not represent separate components or stages of the transparency arrangement.

4.2.1. From farm data to trustworthy lot-level transparency

Analytical aspect	Application within the analytical thread
Focal purpose and object	Sufficiently complete and credible farm records structured into a Production Lot that allows downstream actors to inspect product origin and associated production history, supports product traceability and product/quality assurance, and provides the data basis for associated sustainability information.
Stakeholders and relationships	**Farmers** produce much of the underlying information and carry out the associated recording work, while **Agricolus** configures the formal categories, calculations, structures, and public presentation through which those activities are represented. **Independent agronomists** contribute professional expertise, co-design, and farmer support, while **Agricolus agronomists** also contribute to monitoring, review, correction, and data-quality support. **Downstream professionals** rely on the resulting lot information for traceability and assurance. **Agricolus** depends on continued farmer participation and sufficiently complete records, while **farmers** depend on usable infrastructure, perceived value and appropriate organisational or economic support. Therefore, the arrangement combines interdependence with asymmetries in configurational control and data-production burden.
Requirements	Farm data collection needs to remain sufficiently simple and low burden for consistent use in ordinary work. Lot records need sufficiently complete and coherent

	production information to reconstruct what happened to a lot and support derived information. Production, sustainability, and quality information also need to retain crop-specific meaning, where different crops and supply chains require different information structures. Appropriate boundaries between farm records and externally disclosed information remain relevant when the completed lot becomes publicly visible.
Challenges	Repeated farm data production can create workload and participation challenges, particularly when the perceived value of recording is weak. Partial records, forgotten operations, and differences in digital experience can reduce completeness. Automatic field capture can be disrupted under field operating conditions. A common architecture also needs to accommodate different crops, farm practices and supply-chain information needs without assuming that one fixed specification is adequate everywhere.
Tensions	Lower recording burden needs to coexist with sufficiently continuous and complete data production. Automatic capture can reduce farmer effort and provide a more direct capture pathway, while manual fallback remains necessary for field resilience. A reusable common architecture needs crop-specific specification to preserve agronomic and product meaning. Public accessibility increases downstream visibility while also making information selection and disclosure conditions more consequential.
Material configurations	Geo-referenced field/master data provide crop, variety, cultivation method, irrigation, and field context. Crop operations record activity type, date, inputs, quantities, and duration. AgriPlug can capture operation duration automatically, with manual duration entry available when automatic capture is disrupted. The Production Lot links harvested quantity and a unique lot code to field-level production history. Sustainability indicators are calculated from operational records, while crop-specific data structures and controlled vocabularies configure quality, certification and transport information for tomato and rice. Selected information becomes visible through the public QR layer, creating a private/public boundary between farm-management records and externally accessible Production Lot information. Farmer participation, training, repeated contact, agronomist monitoring, review, and correction also form part of the configuration through which record completeness and credibility were maintained.
Fit-for-purpose relationships	Lot code, producer and field information, operations, quantity, quality/certification/transport attributes, and associated sustainability information can be sufficient for downstream inspection of production history when the underlying farm records are sufficiently complete and credible, and participation and support conditions sustain their production and maintenance. No explicit quantitative threshold defines this relationship. Structured, reviewed, or automatically calculated information does not mean that every underlying farm event has been independently verified, and the credibility of derived information remains dependent on the completeness and accuracy of its source records.

Reconfigurations	Significant configuration choices include embedding traceability within the existing DSS, using the Production Lot as the principal aggregation boundary, automatically deriving sustainability indicators from operational records, retaining a hybrid Agriplug/manual capture configuration, using public QR access without an account, applying crop-specific specifications within a common architecture, and actively supporting farmer participation. Seasonal feedback led to the refinement of tracked irrigation, quality, and sustainability information, while training, monitoring, correction, and fallback practices improved incomplete records during the pilot. Selected farm information also became externally visible through the QR layer, extending an arrangement that was previously more strongly centred on farmer-controlled farm information.

Table 9. From farm data to trustworthy lot-level transparency

Interconnections within the thread

Lot-level transparency in the Agricolus arrangement depends on more than the existence of a Production Lot record or QR interface. Farmers produce much of the information from which the representation is constructed, while Agricolus determines the formal structures, calculations, and interfaces through which that information becomes organised and externally visible. Therefore, the quality of the resulting Production Lot depends simultaneously on participation, recording burden, data-capture mechanisms, agronomic interpretation, and the structures used to associate field activities with the relevant harvested lot. The Production Lot provides a coherent aggregation boundary for otherwise dispersed farm information, but its usefulness for downstream traceability remains connected to the completeness and credibility of the records from which it is constructed.

The combination of automatic and manual capture illustrates these interdependencies. AgriPlug can reduce recording effort through automatic operation-duration capture, while manual fallback preserves continuity when automatic capture is disrupted under field conditions. Training, repeated contact, agronomist monitoring, review, and correction also helped address incomplete or inconsistent records during the pilot. Use across three seasons provided evidence of operational fit without independently validating every underlying record. These support conditions formed part of the configuration demonstrated in the pilot. Professional support can also form part of commercial use where needed, while its intensity and form may vary across deployments. Therefore, scaling may require a different combination of onboarding, professional support, and selective automation.

The same relationship extends to calculated and publicly disclosed information. Sustainability indicators can reduce the burden of separate reporting by deriving representations from operational records, but errors or omissions in those records can propagate into the resulting indicators. Agricolus and INRAE contributions support the methodological appropriateness of the sustainability

representation, while agronomist review strengthens record completeness and consistency; neither independently verifies the factual truth of every underlying farm event. Crop-specific configuration provides another important condition: tomato and rice share the same overall Production Lot architecture while retaining different quality, certification, water-use, and other information structures. Seasonal feedback and co-design have also altered which information is recorded and represented. Consequently, a trustworthy lot-level representation rests on the interaction between reusable architecture, crop-specific meaning, farmer participation, human and technical assurance practices, and the downstream purpose for which the resulting lot history is inspected.

4.2.2. Public sustainability disclosure, selection, and interpretation

Analytical aspect	Application within the analytical thread
Focal purpose and object	Relevant sustainability and associated product information from the Production Lot is selectively made visible and interpretable to downstream professional and consumer audiences to support sustainability communication and trust.
Stakeholders and relationships	**Farmers** generate much of the operational information from which sustainability representations are derived and are also represented through the disclosed information. **Agricolus** configures the indicator calculations, crop-specific information structures, information categories, and public presentation. **Buyers, processors and other downstream professionals** may use sustainability information in relation to product, quality or sustainability assurance, while **consumers** form a public audience with different interests and attention constraints. **Agronomists** contribute to the credibility and agronomic meaning of the underlying records, and **INRAE** contributes to the methodology and assessment of sustainability indicators. These actors do not necessarily require the same information or explanatory depth from the public transparency layer.
Requirements	Sustainability and related product information should preserve crop-specific meaning and remain relevant to the intended downstream stakeholder and use. Publicly disclosed information should be sufficiently selective and understandable to support appropriate interpretation. Farmer-owned farm records also require appropriate boundaries between information retained within the farm-management environment and information deliberately made public.
Challenges	The platform can hold more production and sustainability information than is necessarily useful to disclose to every audience. Raw indicator values may be difficult to interpret without information about their basis, production context or appropriate comparison. Professional and consumer audiences can also differ in the information they consider relevant.
Tensions	Greater technical visibility can increase access to farm, product, and sustainability information while also increasing the need for selection, contextualisation, and

	disclosure control. A simple QR experience supports low-friction access, while additional explanatory information can increase complexity. A common Production Lot architecture supports reuse across crops, while meaningful sustainability and quality disclosure requires crop- and context-specific specification. Public visibility may support sustainability communication and trust while also increasing comparison, scrutiny, or the risk of misinterpretation.
Material configurations	Sustainability indicators are calculated from operational records, including information concerning water, fertiliser, treatments, and yield. Crop-specific data structures and controlled vocabularies allow tomato and rice Production Lots to present different quality-, certification-, transport- and sustainability-related information within a common architecture. Selected information is presented through a publicly accessible QR landing page, while incomplete sections are not rendered. This creates a private/public governance boundary in which farmer disclosure control is exercised primarily through the configuration of the Production Lot before publication. Methodological input from Agricolus and INRAE supports the structure and relevance of the sustainability indicators, while calculated values remain dependent on the underlying farm records. An external evaluation involving 21 stakeholders provides evidence of perceived utility, trust, and adoption potential rather than demonstrated downstream behaviour.
Fit-for-purpose relationships	Sustainability information can be sufficient for public communication when the disclosed set is relevant to the intended audience and use and is accompanied by enough production or agronomic context for appropriate interpretation. No explicit quantitative threshold defines this relationship. Maximum disclosure and raw numerical values are not automatically sufficient, and information adequate for a professional buyer need not be adequate in the same form for a consumer. Calculation or methodological alignment does not independently establish the factual accuracy of every underlying lot-level input or prove environmental performance.
Reconfigurations	Agricolus derives sustainability information from operational records rather than requiring a separate reporting process, and the Production Lot uses selective public QR disclosure without requiring an account. Seasonal feedback and market needs led to the refinement of irrigation, quality, and sustainability information, while tomato and rice demonstrate crop-specific specifications within a common architecture. The move from predominantly farmer-controlled farm records to selected public lot information increased the importance of disclosure selection and interpretation. Existing sustainability-indicator and target-comparison functions provide a basis for further contextualisation of the public representation, while expansion to additional crops or audiences may require further specification of content and presentation.

Table 10. Public sustainability disclosure, selection, and interpretation

Interconnections within the thread

Public sustainability transparency in the Agricolus arrangement depends on the relationship between what farm information exists, how it is transformed into sustainability representations, what is

selected for disclosure, and what different audiences can reasonably understand from it. Operational farm records provide the basis for calculated indicators, while crop-specific configurations determine which forms of sustainability, quality, and product information remain meaningful for tomato and rice. The public QR layer then changes the visibility of this information by making selected Production Lot content accessible outside the farm. These material choices are closely connected to the positions of the actors involved: farmers generate and are represented through much of the underlying information, Agricolus configures the calculations and public presentation, and downstream professionals and consumers encounter the resulting representations for different purposes.

Consequently, technical availability is not equivalent to fit-for-purpose disclosure, and making all available information public would not necessarily provide more usefulness. Professional users may need particular production details, indicator bases or assurance information, while consumers may require a smaller set of understandable information and sufficient context to interpret what a value means. Contextualisation and reference values could respond to this interpretive boundary. Methodological input from Agricolus and INRAE and the external evaluation support the relevance and perceived usefulness of the representation, but neither independently verifies underlying farm inputs nor demonstrates particular purchasing or trust outcomes.

Selection also has a governance dimension, because the Production Lot arrangement moves information from a farm-management environment towards selective public visibility via the QR layer. This reconfiguration makes decisions about what becomes public, for which audience, and with what explanatory context increasingly consequential. Farmer control over public disclosure is exercised mainly through configuration of the Production Lot before publication. This clarifies where disclosure control is located within the current arrangement, while the selection and contextualisation of information for different audiences remain relevant to fit-for-purpose public transparency.

4.2.3. Making farmer contribution visible

Analytical aspect	Application within the analytical thread
Focal purpose and object	Working-time information, particularly crop-operation duration, is made visible as a representation of farming effort, with the aim of making otherwise poorly visible producer contributions more apparent in downstream value-chain interactions.
Stakeholders and relationships	**Farmers** perform the activities being represented and contribute to the records from which the operation duration is derived. **Agricolus** configures the capture mechanisms, data structures and interfaces through which duration becomes associated with the Production Lot and made visible. **Agronomists** can support data capture and interpretation where necessary. **Downstream buyers and other**

	professional actors form the principal intended audience for using duration as information about farming activity. In this regard, the arrangement makes one aspect of **farmers'** work more visible to **downstream actors** who are otherwise removed from the production process and is intended to reduce an information asymmetry concerning farming effort. The available evidence does not establish that this visibility has changed bargaining power or other downstream outcomes.
Requirements	Operation-duration information needs to be captured with sufficient reliability and enough contextual meaning to function as evidence of farming effort. Recording should remain compatible with ordinary farm work and retain continuity when automatic capture is unavailable. The representation also needs to avoid implying meanings that duration alone cannot establish.
Challenges	Automatic capture can be disrupted under field conditions, whereas manual recording adds workload and relies on consistent farmer participation. Duration also varies with operation type, crop and field characteristics, production method, machinery and other contextual factors, making raw hours difficult to interpret consistently across farms or activities.
Tensions	A simple working-time measure can make previously less visible farming activity readily communicable, while the same simplicity can encourage interpretation beyond what the measure establishes. Automation can reduce recording burden and provide a more direct capture pathway, while manual fallback remains necessary for resilience. In this sense, greater visibility of farming work coexists with uncertainty about how downstream actors understand or value the information. Public visibility of working-time information also makes the conditions under which farmer-owned information becomes publicly disclosed consequential.
Material configurations	Crop-operation records contain operation type, date, inputs, quantities and duration. AgriPlug can capture operation duration automatically, with manual duration entry available when automatic capture is disrupted. Duration is associated with the relevant Production Lot and presented as working-time information via the public QR layer. These automated and manual pathways differ in how duration is captured and remain dependent on sufficiently complete underlying operation records. Therefore, its public presentation also operates within the wider private/public disclosure boundary of the Production Lot arrangement.
Fit-for-purpose relationships	Operation duration can be sufficient to make farming effort and time visible and communicable. No explicit quantitative threshold defines this relationship. Duration does not, by itself, establish the value, efficiency, quality, or sustainability of the work performed. The visibility of duration may provide input for further comparison or valuation, but such stronger interpretations require additional contextual information and are not established by duration alone. In this sense, the meaning depends on the type of operation, field and crop characteristics, machinery, production method, and the purpose for which downstream actors interpret it.

Reconfigurations	Farmer and user feedback identified operation duration as information that could make farming contributions more visible within the Production Lot arrangement. Within the pilot, AgriPlug was used as an automatic duration-capture pathway alongside a dedicated manual-entry option. This hybrid configuration preserved duration information when automatic capture was disrupted, while public QR disclosure made the resulting representation accessible beyond the farm.

Table 11. Making farmer contribution visible

Interconnections within the thread

Operation duration became relevant to transparency because the time involved in farming activities has been difficult for downstream actors to observe directly, but it could be represented using information already linked to crop-operation records. Farmer and user feedback contributed to making operation duration a more explicit transparency object within the Production Lot arrangement, using AgriPlug and related recording mechanisms to capture and communicate that information. The resulting transparency object thus reflects an interaction between stakeholder interests, existing technical capabilities, data-production practices and a particular purpose: making farming work more visible outside the farm.

The credibility and meaning of that representation remain connected to how duration is produced and interpreted. AgriPlug can reduce manual recording and provide a more direct capture pathway, while manual fallback preserves continuity when automatic capture is disrupted under field conditions. Both pathways become part of the Production Lot configuration, and the visibility of working-time information remains dependent on the completeness of the operation records. At the same time, making duration visible does not determine what that duration means. The same duration may carry different meanings depending on the operation performed, field and crop characteristics, machinery, and production method. In this context, the fit-for-purpose relationship is bounded by the visibility of farming effort. Duration may provide input for further assessment, but it does not establish the value on its own.

This distinction is particularly important because increased visibility can create new possibilities for interpretation without establishing how downstream actors actually use the information. Duration may support discussion of farming activity or producer contribution, but the case evidence does not establish that working hours are already used to determine economic value, bargaining outcomes, sourcing decisions, production quality or sustainability performance. Contextual information concerning the operation, field or production conditions may consequently become important where duration is expected to support a stronger interpretation than simple visibility of time spent.

4.2.4. Findings and suggestions

Finding	Implication
Lot-based transparency is produced through an interconnected socio-technical configuration rather than by the QR feature alone. The Production Lot depends on farm records, crop-specific structures, indicator calculations, farmer participation, agronomist support, data-quality practices, and selective QR disclosure.	The credibility and usefulness of the public lot representation depend on the wider configuration through which the underlying information is produced, structured, reviewed, and disclosed. Reconfiguration of consequential elements may thus alter what the Production Lot can support for particular purposes.
Farmer participation and human-supported data quality form part of the transparency configuration demonstrated in the case. Training, repeated contact, agronomist monitoring and review, correction, and manual fallback contributed to sufficiently complete and consistent lot records during the pilot.	Scaling the arrangement requires attention to how the functions that support participation and data quality are preserved, redistributed or automated. Professional support can also form part of commercial use where needed, but the evidence does not imply that the same intensity or form of support is universally required across deployments.
Public sustainability transparency encounters a selection and interpretation boundary. Technically available farm information is not automatically useful in full, and the relevance of sustainability information depends on what is disclosed, to whom, for what purpose, and with what contextual information.	Public disclosure benefits from preserving the accessibility of the QR interface while providing enough crop, production, indicator or comparative context for appropriate interpretation. Professional and consumer audiences may not require the same information or explanatory depth.
Operation duration makes farming effort visible, but the visibility of effort and its valuation should not be conflated.	Working-time information can convey an otherwise poorly visible aspect of farming activity and may serve as input for further comparison or valuation. However, duration alone does not establish the value, efficiency, quality or sustainability of that activity. Stronger interpretations depend on additional context and on how downstream actors actually use the information.
Farmer control over public disclosure is concentrated in the Production Lot configuration before QR publication.	Farmer control is concentrated in how the Production Lot is composed before publication, while the public QR representation reflects the configured lot. This clarifies where control over public visibility is allocated within the arrangement.

Table 12. Main findings from the Agricolus case

Suggestion	Intended contribution	Conditions and trade-offs
Develop an explicit and scalable assurance/support configuration around Production Lot completeness and consistency, building on the human and technical functions demonstrated in the case. Possible elements could include automated completeness and consistency checks, capture-source indicators, missing- or corrected-record flags, targeted farmer/agronomist review, and clearer conditions for lot readiness.	Preserve the participation and data-quality functions that supported credible Production Lot records while reducing dependence on intensive project-based support as adoption expands.	The configuration should build on existing Agricolus controls and distinguish which functions sustain participation and data production, which require professional judgement, and which can realistically be automated. Excessive checking or alerts could recreate the administrative burden that the arrangement seeks to reduce. Therefore, additional assurance information should be audience-appropriate.
Further contextualise publicly disclosed sustainability information according to audience and use, building where relevant on existing indicator and target-comparison functions. This could include indicator meaning and basis, production context, comparison boundaries or reference values, and different levels of detail where professional and consumer needs differ.	Retain the low-friction accessibility of QR disclosure while reducing the risk that sustainability values are interpreted without sufficient context or compared inappropriately.	Contextualisation requires defensible reference points and decisions about which distinctions between audiences are useful. Additional explanation can complicate a deliberately simple public interface, while benchmarks or comparison frames may introduce their own assumptions.
Where operation duration is used to communicate farmer contribution or support comparison, accompany it with enough contextual information to clarify what the recorded time represents. Relevant context may include operation type, field or lot characteristics, cultivation method, manual or mechanised activity, production stage, or capture method.	Strengthen the interpretability of working-time information while preserving its value as a relatively simple representation of farming activity.	The appropriate context depends on what farmers and downstream users expect the information to communicate. Additional detail can reduce the simplicity of the representation, yet it cannot capture every qualitative dimension of effort or value.

Table 13. Main suggestions for the Agricolus case

The Agricolus case shows how lot-level digital transparency depends on the interdependence of farm data production, farmer and agronomist participation, technical capture and calculation, crop-specific representation, selective disclosure, and downstream interpretation. The Production Lot provides a common structure within which these elements are configured, while the tomato and rice variants demonstrate the need for contextual specification within that structure. The case also shows that making information visible does not determine what that information can reasonably support:

sustainability information requires appropriate selection and contextualisation, while operation duration can make farming effort visible and provide an input to further assessment without, by itself, establishing its value. In this context, reconfiguration concerns both the conditions needed to sustain credible data production as the arrangement scales and the ways in which different publicly visible representations remain meaningful for their intended uses.

4.3. QualityChain Case

The QualityChain case focuses on the **product-provenance and authenticity transparency arrangement** through which agri-food SMEs register and communicate product- and lot-level information using QR-linked digital interfaces. Blockchain-based integrity mechanisms make registered traceability events independently inspectable, while a separate cryptographic and steganographic configuration provides stronger verification of a protected product/lot-linked QR identity. Therefore, the focal arrangement combines consumer-facing provenance visibility with different mechanisms for examining the integrity, evidentiary basis, and authenticity of specific representations.

Two principal sub-configurations are distinguished: **Blockchain traceability/provenance** structures contributions from producers and other supply-chain actors into lot-specific Entity/Event histories linked to blockchain registration and integrity evidence. **Protected-code verification** combines an ordinary visible QR with a cryptographically signed hidden payload and a dedicated verification mechanism intended to support anti-counterfeit authentication. Ordinary QR interaction remains available for low-friction product and provenance access, while the stronger protected-code check operates as a distinct verification pathway.

Element	Description
Transparency purpose and objects	Product-lot provenance and recorded production/supply-chain history; integrity and registration status of traceability events; authenticity/validity of a protected product/lot-linked QR identity.
Intended uses	Enable consumers and downstream actors to inspect recorded product provenance; allow independent checking of registration and post-registration record integrity; provide stronger verification of a protected product/lot-linked identity; enable these mechanisms to remain usable and affordable for agri-food SMEs.
Main actors and roles	**QualityChain** configures the traceability model, blockchain architecture, QR interfaces and protected-code mechanisms. **SME producers and other supply-chain contributors** provide substantive product and event information and remain responsible for the claims they contribute. **Consumers** are the principal intended

	recipients of QR-linked product and provenance information and may use the stronger protected-code verification route. **Downstream assurance actors**, including certification or quality actors where relevant, may inspect provenance or provide additional evidence supporting substantive claims. **Packaging, printing and integration actors** affect the material deployment and recoverability of protected codes.
Information made visible or verifiable	Actors, products/lots, transformations, event types, timestamps, and locations; recorded lot histories; blockchain transaction and integrity evidence; product information; validity of the signed hidden payload associated with a protected QR identity.
Principal sub-configurations	Blockchain traceability/provenance; protected-code verification.
Outputs and access	Producer Dashboard/event-entry workflow; QR-linked product/lot page and event history, with registered events linked to public EVM transactions for independent inspection; artistic signed/steganographic QR; dedicated protected-code verifier.
Scope boundaries	The case concerns the QualityChain provenance and protected-code arrangement rather than blockchain technology generally. It does not treat blockchain integrity as proof of the factual truth of all producer claims, equate the complete set of recorded events with a complete physical product journey, or assume that successful verification of a protected code alone proves the genuineness of the physical product carrying it. The analysis also does not infer consumer purchasing effects or price premiums, establish universal regulatory compliance, assess the complete cybersecurity posture, or generalise performance across every packaging/device environment.

Table 14. Overview of the focal digital transparency arrangement of the QualityChain case

The case analysis centres on three interconnected threads: **from tamper-evident records to sufficient provenance**, **low-friction SME and consumer transparency**, and **protected-code authenticity verification under real-world conditions**. The first examines how different forms of integrity, substantive assurance, and provenance continuity interact; the second examines the conditions under which producers and users can practically sustain and access these configurations; and the third examines how protected-code verification depends on both digital and physical deployment conditions.

4.3.1. From tamper-evident records to sufficient provenance

Analytical aspect	Application within the analytical thread
Focal purpose and object	A product-lot history whose recorded events can be inspected and whose blockchain-bound representations are tamper-evident, while retaining distinctions between the integrity of the registered record, the credibility of the substantive claim represented by that record, and the completeness of the recorded provenance journey.
Stakeholders and relationships	**Producers and other supply-chain contributors** provide the substantive information represented in traceability events, while **QualityChain** determines how these contributions are formally structured, registered, and made inspectable. **Consumers and downstream actors** depend on the resulting representation to inspect provenance. **Certification or other assurance actors** may provide separate evidence supporting particular substantive claims. **Relevant supply-chain actors** are also interdependent because a multi-stage provenance history depends on their respective contributions being connected. In this regard, **QualityChain** exercises substantial configurational influence while substantive claim responsibility and provenance production remain distributed across the arrangement.
Requirements	Traceability events need sufficiently strong registration integrity, timestamping, and auditability for independent checking. The product-lot history also needs enough relevant actors, events and relationships to represent the provenance journey for its intended use. Contributions should remain attributable to their source, while stronger substantive claims may require additional evidence or assurance beyond blockchain registration. The underlying structure also needs sufficient adaptability to represent different supply chains without requiring a complete redesign.
Challenges	Blockchain integrity does not establish the factual truth of the original producer or contributor statement. Provenance continuity also depends on relevant information being contributed and retained across organisational boundaries: technically valid records can represent only the information that enters the system. Different chains also involve different actors, transformations, and reporting requirements, creating a challenge in maintaining a reusable structure without removing context-specific meaning.
Tensions	Technical immutability and independent auditability strengthen one dimension of credibility, whereas substantive assurance depends on the contributing actor and any supporting certification or evidence. A structured event history can make recorded provenance highly inspectable while still requiring sufficient participation and information continuity for that history to represent the relevant physical journey. A generic traceability structure supports cross-chain reuse, while sector- and country-specific requirements can still require contextual configuration.
Material configurations	Producers enter traceability events through the Producer Dashboard, while the Entity/Event model structures companies, locations, products/lots, transformations,

	event information, and lot relationships. Registered events are bound to public EVM transactions and integrity evidence, and the consumer-facing history provides a route to inspect the corresponding transactions. Certification or other external evidence, where present, remains separate from blockchain integrity.
Fit-for-purpose relationships	Blockchain transactions and integrity evidence can be sufficient to establish that a particular event was registered and that its registered representation has not subsequently been altered. A structured Entity/Event history can be sufficient for reconstructing recorded product-lot provenance when relevant actors, stages and information are represented and connected. These relationships remain distinct: registration integrity does not establish the factual truth of every substantive claim, and the complete set of technically valid recorded events does not necessarily constitute a complete representation of the relevant physical product journey.
Reconfigurations	QualityChain developed from QR-based product storytelling and blockchain notarisation of product-level information towards structured lot-specific, multi-actor provenance. Within TITAN, the Entity/Event architecture formalised this shift by representing actors, lots, transformations and events as a connected history. Public-blockchain integrity, a generic cross-chain model, and distributed assurance roles became important design choices within this configuration. Extension from three supply-chain demonstrations to a fourth chain, including pickled olives, retained the generic structure while reinforcing the need to configure sector- and country-specific reporting requirements in context.

Table 15. From tamper-evident records to sufficient provenance

Interconnections within the thread

QualityChain's provenance configuration shows how provenance credibility is produced through the interaction of stakeholder responsibilities, material structuring, technical integrity, and substantive assurance. Producers and other contributors determine the substantive event content, while QualityChain determines how those contributions are structured through the Entity/Event model, registered, and made inspectable. Public blockchain transactions protect the integrity of the registered representation after entry, while certification, audit or other evidence can perform a separate substantive-assurance function. In this regard, the fit-for-purpose question concerns whether the combination of attributable contributions, technical integrity, and any necessary supporting assurance is sufficient for the intended provenance use.

The same relationship extends from individual records to the completeness of the product-lot history. The Entity/Event configuration can connect actors, events, lots, and transformations, but the resulting provenance depends on relevant supply-chain actors actually contributing the information needed to represent the intended journey. The trials demonstrated that event entry, blockchain registration, and consumer lookup can operate together. On the other hand, these trials did not demonstrate end-to-

end multi-company provenance. While this does not weaken the integrity of the records that were registered, it shows that fit-for-purpose provenance depends simultaneously on technical integrity, stakeholder participation, and information continuity. Because the consumer page does not signal absent stages or actors, the material presentation of the history also affects what downstream users can reasonably infer about its scope.

Reconfiguration altered these relationships by shifting the focal transparency object from product-level communication and notarisation towards structured lot-specific, multi-actor provenance. Representing actors, events, lots, and transformations increased the importance of contribution across organisational boundaries, attribution of claims, and contextual specification of relevant stages. The reusable Entity/Event architecture supports transfer across product chains, but its fit remains conditional on which actors, events, and sector- or country-specific meanings need to be represented. Consequently, the same technical structure can remain relatively stable while stakeholder participation, information requirements, and contextual configuration determine whether the resulting provenance is sufficient for its intended use.

4.3.2. Low-friction SME and consumer transparency

Analytical aspect	Application within the analytical thread
Focal purpose and object	A provenance transparency arrangement that small producers and relevant supply-chain actors can practically populate and sustain, while consumers and downstream users can access the resulting product and lot information without unnecessary technical friction.
Stakeholders and relationships	**SME producers and other supply-chain contributors** produce much of the substantive information and carry the associated registration effort and cost, while **QualityChain** configures the workflows, infrastructure and interfaces through which this information becomes structured and visible. **Consumers** principally receive the resulting visibility through ordinary QR interaction. Where provenance spans several organisations, its continuity also depends on contributions from multiple actors. Therefore, the arrangement connects producer participation and perceived value with downstream accessibility, while the actors carrying the data-production burden are not necessarily those receiving the resulting visibility.
Requirements	Producers need to enter and register traceability information without a disproportionately burdensome or highly technical workflow. The cost and effort associated with transparency need to remain proportionate to its expected value for small producers. Where provenance spans multiple organisations, the contribution workflow also needs to remain workable across relevant actors so that information continuity can be maintained. Consumers should be able to access ordinary product and provenance information without specialist applications or technical knowledge.

	The configuration also needs sufficient flexibility to accommodate different supply-chain settings without requiring a complete redesign.
Challenges	Additional assurance and traceability requirements can increase producers' effort, integration complexity, and costs. Producers also evaluate transparency against its perceived commercial or operational value, which can affect continued participation even where the technical configuration functions as intended. Multi-actor provenance introduces an additional dependency because reducing the burden for one producer does not ensure that relevant information is contributed across other stages. Different supply chains may also require contextual adaptation despite using a common architecture.
Tensions	Stronger assurance and more extensive provenance information can increase credibility while also increasing cost, workload and complexity. Low producer burden supports participation, while sufficient provenance may require contributions from several actors. Ordinary QR access minimises consumer interaction friction, while stronger protected-code verification requires a separate verification pathway. A generic architecture supports reuse across chains, while sector- and country-specific requirements still need contextual specification. Flexible EVM deployment can support affordability and network choice, while different deployment choices may entail varying cost, performance, and auditability characteristics.
Material configurations	Producers use the existing QualityChain workflow and Producer Dashboard to enter traceability events. Gas-optimised event logs and flexible EVM deployment reduce the blockchain registration cost for the traceability configuration. The generic Entity/Event architecture allows the same underlying structure to be used across different product chains, while the QR-linked product/lot page provides ordinary consumer access without requiring a dedicated application. The ordinary QR interaction is retained even where the protected-code configuration is present, separating routine transparency access from the optional stronger verification mechanism.
Fit-for-purpose relationships	The practical operation of provenance transparency depends on producers and relevant supply-chain actors being able and willing to contribute the required information at proportionate cost and effort, while downstream access remains sufficiently low-friction. These conditions affect whether the provenance relationships examined in the previous thread can be sustained in practice: technically verifiable infrastructure alone is insufficient where participation, information contribution or low-friction access cannot be maintained.
Reconfigurations	SME cost, usability, perceived business value and production-integration requirements shaped the move towards gas-efficient event registration, flexible EVM deployment, phased production integration and preservation of the existing QualityChain producer workflow. Ordinary QR scanning was retained as the default consumer interaction. As the arrangement expanded across different supply chains, including the addition of pickled olives, the generic architecture was maintained while

	sector- and country-specific requirements remained matters of contextual configuration.

Table 16. Low-friction SME and consumer transparency

Interconnections within the thread

The QualityChain case shows that practical production of provenance information depends on acceptable cost and effort. Affordability and low friction were primary design drivers, reflected in gas-efficient registration, preservation of the existing producer workflow, and ordinary QR access. At the same time, onboarding remains hands-on: QualityChain creates the account, supports initial company and product setup, and assists with the first events, after which producers use the dashboard independently during the field trials. In this context, low blockchain registration costs address only part of the implementation burden, and set up, ongoing event recording, and the commercial service relationship remain consequential. Because producers and other contributors carry much of this burden while downstream users receive much of the resulting visibility, participation is not merely an implementation issue. It is a fit-for-purpose condition for maintaining the information continuity on which provenance depends.

Low friction is equally relevant on the receiving side of the arrangement. Consumers can access the QR-linked product and provenance information using ordinary QR interaction, avoiding a requirement for specialist applications for routine transparency. QualityChain retains this interaction even when the stronger protected-code mechanism is present. This creates a layered user configuration in which ordinary access remains simple while stronger verification is available through a separate route. In this context, the two functions address different requirements: accessibility supports routine visibility, while the dedicated verification configuration addressed in the following thread provides an additional assurance mechanism.

The same design logic also affects expansion across products and supply chains. The generic Entity/Event architecture reduces the need to rebuild the traceability structure for each chain, while experience across different chains shows that reusing the technical structure does not eliminate sector- and country-specific requirements. Cost, producer workflow, participation, consumer accessibility, and contextual adaptability consequently operate together as conditions under which the provenance configuration can remain workable as it is transferred or extended.

4.3.3. Protected-code verification under real-world conditions

Analytical aspect	Application within the analytical thread
Focal purpose and object	A protected product/lot-linked QR identity whose hidden cryptographically signed payload can be recovered and verified under representative physical-use conditions, while the same code remains usable for ordinary QR access. The focal verification object is therefore the protected signed mark associated with the referenced product/lot identity.
Stakeholders and relationships	**QualityChain** configures the protected-code generation, embedding and verification mechanisms, while producers apply the resulting codes within product and packaging contexts. **Packaging, printing and integration actors** affect the material conditions under which the protected mark is reproduced and recovered. **Consumers or other verifier users** interact with either the ordinary QR pathway or the stronger protected-code verification pathway. Therefore, the arrangement depends on coordination between digital configuration and physical production conditions, while **QualityChain** retains substantial configurational influence over what a successful verification result represents and how it is communicated.
Requirements	The protected signal needs to remain sufficiently recoverable and cryptographically verifiable across representative printing, packaging, device, and capture conditions. These properties need to coexist with ordinary QR scanability and acceptable visual presentation. Ordinary product and provenance information should remain accessible without requiring the dedicated protected-code verification pathway.
Challenges	Physical reproduction and capture conditions can affect hidden-mark recovery even where the underlying cryptographic mechanism remains unchanged. Printing methods, substrates, image quality, lighting, and user devices introduce variation outside the purely digital configuration. Stronger embedding can improve recoverability while affecting visual appearance or ordinary QR performance. A further boundary concerns the relationship between verification of a valid protected mark and the genuineness of the physical product carrying it.
Tensions	Increasing protected-mark robustness can conflict with aesthetic requirements and ordinary scanability. Maintaining low-friction ordinary QR access creates a two-level user journey in which stronger verification requires an additional interaction. Cryptographic verification strengthens confidence in the protected digital/printed identity, while physical-product authenticity additionally depends on how securely that identity remains bound to the product on which it appears.
Material configurations	The protected-code configuration combines an artistic/brandable visible QR layer with a cryptographically signed hidden steganographic payload associated with product/lot identity and a blockchain time reference. Error-correction and recovery mechanisms, a dedicated verifier and defined physical design conditions support recovery and verification of the protected signal after printing and capture. The same

	printed code remains accessible through ordinary QR applications for routine product information, while the dedicated verification route performs the stronger protected-mark check. Physical packaging, printing, and capture conditions form part of the material configuration rather than operating only as external deployment factors.
Fit-for-purpose relationships	Under the tested material conditions, the hidden signed payload can be recovered and verified while ordinary QR access remains available. A successful result establishes that the protected code carries a valid issuer signature associated with the expected destination and has not been altered in a way that invalidates that signature. This verifies the protected code, but it does not, by itself, establish the genuineness of the physical product carrying it or resistance to every possible form of copying or reuse.
Reconfigurations	Testing across print methods, substrates, devices, and capture conditions led to stronger recovery and error-correction mechanisms, a dedicated verifier, and physical design guidance, while preserving ordinary QR functionality. These adaptations improve protected-mark recovery under the tested conditions without removing the boundary between successful code verification and stronger claims concerning copying/reuse resistance or physical-product genuineness.

Table 17. Protected-code verification under real-world conditions

Interconnections within the thread

Protected-code verification illustrates particularly clearly how the performance of a digital transparency mechanism depends on its wider material configuration. Multi-device, multi-browser and multi-substrate testing provided technical evidence for recovery and ordinary QR scanability across the tested configurations. The cryptographically signed hidden payload provides the basis for stronger verification, but its practical recoverability is also shaped by printing, packaging, visual design, capture conditions, and user devices. These dependencies became consequential during testing and led to changes in the recovery mechanisms, the verifier, and the physical design guidance. Consequently, the resulting configuration combines cryptographic protection with material conditions that enable the protected signal to survive the transition from digital code to a printed, and subsequently scanned, object.

These adaptations also had to preserve a second requirement: consumers should still be able to use the same QR code for ordinary product and provenance access. In this context, QualityChain maintains two related interactions within the same physical code. Ordinary applications provide the low-friction transparency pathway described in the previous thread, while the dedicated verifier provides a stronger protected-mark check. This layered configuration allows additional verification capability to be introduced without making specialist verification a prerequisite for routine access, while also making it clear that the two interactions are not to be interpreted as providing the same assurance.

The fit-for-purpose boundary follows from the same configuration. Testing provides strong evidence that the protected mark can be recovered and that its signed payload can be verified under representative physical conditions. That result supports verification of the protected product/lot-linked identity. It does not, by itself, validate the substantive provenance claims associated with that identity, which remain subject to the integrity, assurance, and information-continuity relationships examined in the first analytical thread. The claim that the physical item bearing a valid code is itself genuine also depends on how that protected identity is bound to the product and protected against unauthorised copying or reuse. Therefore, the case distinguishes the demonstrated strength of the protected-code mechanism from the broader anti-counterfeit outcome it is intended to support, while showing how real-world testing and material deployment conditions shaped the configuration needed to provide that stronger verification layer.

4.3.4. Findings and suggestions

Finding	Implication
QualityChain's provenance arrangement distributes assurance across different actors and mechanisms rather than locating it in blockchain registration alone. Producers and other contributors remain responsible for the substantive information they provide, while blockchain registration supports record integrity, and additional certification or evidence can support particular claims.	The credibility of provenance information depends on maintaining distinctions between substantive claim responsibility, supporting assurance, and technical integrity. Blockchain verification should therefore be interpreted in relation to the property it establishes rather than as validation of all information contained in the recorded history.
Tamper-evident records can support reconstruction of recorded provenance, while sufficient provenance also depends on continuity of relevant information across the product journey. The Entity/Event architecture can connect contributions from multiple actors and transformations, but the resulting history represents the information that has been contributed to the arrangement.	Provenance interpretation should remain sensitive to which relevant stages and actors are represented. A complete set of recorded events does not automatically establish that every relevant part of the physical product journey is represented.
Low-friction participation and access form part of the practical provenance configuration. Producers and other supply-chain actors contribute much of the underlying information, while QualityChain's workflow, cost-conscious registration choices and ordinary QR access reduce barriers to producing and accessing that transparency.	Maintaining provenance as the arrangement expands depends on preserving workable contribution conditions and sufficient perceived value for participating actors, alongside accessible downstream use. These conditions become particularly consequential where provenance requires contributions across several organisations.

Protected-code verification adds a distinct assurance layer whose performance depends on both cryptographic mechanisms and physical deployment conditions. Real-world testing of printing, packaging, and capture conditions informed adaptations to recovery, verification, and physical design configurations while retaining ordinary QR functionality.	Successful verification supports the validity of the protected product/lot-linked identity. It does not independently establish the substantive validity of linked provenance claims or all aspects of the genuineness of the physical product carrying the mark.

Table 18. Main findings from the QualityChain case

Suggestion	Intended contribution	Conditions and trade-offs
Where useful, make the different bases of assurance more explicit within the provenance representation, for example, by distinguishing information contributed by producers or other supply chain actors, supporting evidence or certification, and blockchain-verified record integrity.	Help users understand what different parts of the provenance representation are based on and reduce the possibility that technical record integrity is interpreted as substantive verification of every claim. This would reinforce the existing distributed assurance configuration without requiring QualityChain to assume responsibility for independently validating all supply-chain information.	Contributor attribution already exists internally but is not shown to consumers. Per-event certification or audit evidence is not part of the current traceability model, and certification information is producer-declared rather than independently checked by QualityChain. Any added labels should distinguish attribution from external assurance, remain proportionate to the audience, and avoid implying assurance that QualityChain does not provide.
Where provenance continuity is consequential, make the coverage of the recorded history clearer, for example, by indicating which stages or actors are represented, where the available history begins and ends, or by using wording that distinguishes the complete set of recorded events from complete physical-chain provenance.	Clarify the scope of the provenance represented through the Entity/Event history and make information continuity more interpretable where contributions span several organisations. This could support trust in appropriately bounded or partial provenance without requiring every transparency use case to represent the entire supply chain.	A rigid completeness requirement could increase participation burden or discourage useful transparency where only particular stages are relevant to the intended purpose. Therefore, coverage information should reflect the transparency purpose and relevant supply-chain relationships rather than impose a universal definition of complete provenance.
Preserve ordinary QR access as the low-friction route to product and provenance information while making the optional	Maintain accessible consumer transparency while allowing the protected-code configuration to provide an additional verification layer for authenticity and anti-counterfeit	Stronger verification should not become an unnecessary barrier to routine QR access. Its presentation should also avoid implying that successful verification of the

protected-code verification pathway and its role sufficiently clear where stronger identity verification is relevant.	purposes. Clear differentiation between the two interactions can help users understand what the stronger verification mechanism establishes and how it relates to the associated provenance information.	protected mark independently validates all linked provenance claims or establishes every aspect of the physical product's genuineness.

Table 19. Main suggestions for the QualityChain case

The QualityChain case shows how product provenance and authenticity transparency depend on the interdependence of information contributions, traceability structures, integrity mechanisms, participation across organisational boundaries, accessible interfaces, and additional verification mechanisms. The blockchain configuration strengthens the inspectability and post-registration integrity of recorded provenance while leaving substantive assurance distributed across contributing actors and other evidence sources. The protected-code configuration adds a distinct verification layer whose operation is shaped by printing, packaging, and capture conditions alongside its cryptographic design. Across both configurations, the case shows that stronger technical assurance remains connected to the scope and continuity of the information represented, the conditions under which actors can sustain their participation, and the particular property that each verification mechanism is configured to establish.

4.4. TotalCtrl Case

The TotalCtrl case focuses on an **automation-enabled hospitality inventory and food-waste transparency arrangement** through which purchasing and supplier information, physical inventory, expiry-related information, sales/use data, and food-waste events are captured and connected within the TotalCtrl platform. The current inventory configuration combines shelf-level RFID with camera-based capture, while expiry-related visibility is derived from separate inventory data rather than from RFID itself. These information flows are transformed into operational inventory visibility, alerts, procurement information, waste analytics, and managerial and ESG/compliance reporting, with Copilot functionality adding recommendations across purchasing, inventory and waste.

The focal arrangement begins with purchasing and receiving and extends through stock management, use or sales, expiry-related monitoring, and waste to operational and managerial reporting. Two principal transparency sub-configurations are distinguished: **Inventory and procurement transparency** supports visibility of current and expected stock, expiry-related status, purchasing, and ordering information. **Food-waste measurement and reporting** make waste events and patterns

visible for prevention, operational improvement, and sustainability reporting. **Automated capture and cross-system integration** form an enabling layer across these sub-configurations.

Element	Description
Transparency purpose and objects	Current physical inventory, stock movements and expiry-related status; purchasing, supplier, price, and ordering information; food-waste events, quantities/categories and recurring patterns; and operational performance information used for inventory, waste and sustainability management.
Intended uses	Support daily stock and expiry-related management, purchasing and procurement decisions, food-waste prevention and monitoring, and managerial and ESG/compliance reporting within hospitality organisations.
Main actors and roles	**TotalCtrl** configures the data structures, integrations, sensing and capture mechanisms, operational interfaces, alerts, and reporting through which the arrangement operates. **Kitchen staff, chefs, and other operational users** interact with physical stock and waste, review operational outputs, and provide the limited inputs still required by some capture processes. **F&B and procurement managers** use inventory, supplier, purchasing, and consumption information for ordering and cost control. **Management, sustainability, and reporting actors** use integrated inventory, waste, and performance information for management and reporting. **External system and data providers**, including suppliers, procurement, and POS providers, provide or control data and interfaces on which cross-system continuity partly depends.
Information made visible or verifiable	Current and expected stock; expiry-related stock status; purchasing, supplier, price, and ordering information; sales/use movements; food-waste events and trends; operational and cost-related metrics; and information used for sustainability and compliance reporting.
Principal sub-configurations	Inventory and procurement transparency; food-waste measurement and reporting.
Enabling layer	Automated and semi-automated capture and cross-system integration through APIs and other supplier/procurement connections, OCR/document capture, shelf-level RFID combined with camera-based inventory capture, smart-scale camera/weight capture, custom mappings, synchronisation, and quality-control or fallback pathways.
Outputs and access	Operational/mobile inventory interfaces; inventory and waste dashboards; expiry-related and low-stock alerts; procurement information; waste analytics; managerial and ESG/compliance reporting; and Copilot recommendations for purchasing, inventory and waste.

Scope boundaries	The case concerns the last-mile hospitality arrangement from purchasing/receiving through stock, use, and waste to operational and reporting outputs. It does not examine farm-level or wider upstream provenance, consumer-facing transparency, the complete TotalCtrl product portfolio, or the complete cybersecurity/legal-compliance architecture. Shelf-level RFID does not itself establish product-level traceability or expiry; expiry-related information is produced through separate inventory data. The analysis also does not assume error-free sensing, integration or waste classification, or causally attribute reported operational and waste outcomes solely to the digital arrangement.

Table 20. Overview of the focal digital transparency arrangement of the TotalCtrl case

The analysis centres on three interconnected threads: **maintaining digitally continuous inventory visibility**, **low-burden automation with resilient data production**, and **from visibility to operational action and reporting**. The first examines how information distributed across physical stock and external digital systems remains sufficiently connected and current for inventory use. The second examines how increasingly automated capture reduces routine data-production work while leaving a smaller set of technical, external-data and quality-control conditions consequential to inventory and waste transparency. The third examines how integrated information is prioritised and configured for operational decisions, waste management and reporting.

4.4.1. Maintaining digitally continuous inventory visibility

Analytical aspect	Application within the analytical thread
Focal purpose and object	A sufficiently current and meaningful operational representation of what stock is physically available or expected, relevant expiry-related and stock conditions, and incoming and outgoing movements that affect inventory status.
Stakeholders and relationships	**Operational staff** interact with physical stock and review the resulting inventory representation, while **F&B and procurement managers** depend on it for ordering, expiry-related management, and cost control. **TotalCtrl** configures the sensing, integrations, data structures, and interfaces through which these activities become digitally represented. **Supplier, procurement and POS providers** remain infrastructural dependencies where access to external data or interfaces is required.
Requirements	Inventory records need to remain sufficiently current and complete to represent relevant physical stock, expiry-related status and incoming or outgoing movements. Information moving among supplier/procurement, POS and inventory systems needs to preserve sufficient meaning, source information and currentness for operational use. Conditions requiring attention, such as low stock or approaching expiry according to the available shelf-life information, need to become visible in time to support inventory management.

Challenges	Relevant information can exist in an external or internal system while becoming operationally insufficient if it stops flowing digitally, becomes stale or cannot be mapped meaningfully into the current inventory representation. Although many earlier integration problems have been substantially reduced, continuity still depends on customer setup and the ability of third-party supplier/procurement systems to provide usable data. Physical stock visibility also depends on how shelf-level RFID and camera-based capture are combined with product and movement information, while expiry-related status is produced through a separate information pathway.
Tensions	Greater integration can improve continuity while maintaining dependence on external interfaces and supplier data availability. The combined RFID/camera configuration can substantially reduce manual stocktaking while concentrating remaining dependencies in sensing performance, system configuration and quality control. Reuse of a common platform supports scaling, while heterogeneous external systems and customer environments continue to require contextual configuration.
Material configurations	Supplier and procurement integrations and alternative order-document capture routes bring purchasing, supplier, quantity, and ordering information into the platform. The current physical inventory configuration combines shelf-level RFID with camera-based capture rather than relying on product-level RFID tags. Expiry-related information is produced through separate inventory data rather than RFID. POS/sales integrations connect outgoing product use or sales to the wider inventory representation. Custom mappings and synchronisation align heterogeneous data flows within the consolidated platform, while operational interfaces, dashboards, and alerts present the resulting inventory state.
Fit-for-purpose relationships	Inventory information can be sufficient for stock control, expiry-related management, ordering, and prioritisation when the combined physical capture, purchasing, and movement information remain sufficiently current and meaningfully connected, and when the shelf-life information used for expiry-related status is sufficiently applicable to the products concerned. No single capture mechanism can establish the complete operational state; the usefulness of the inventory representation depends on the configured relationships among sensing, external data, movement information, and quality-control processes.
Reconfigurations	TotalCtrl developed the arrangement around integration with existing hospitality systems rather than requiring replacement of the wider technology environment. Manual stocktaking burden initially motivated RFID-enabled counting, while operational experience showed the limitations of relying on RFID for product-level tracing and expiry. The inventory configuration consequently evolved towards shelf-level RFID combined with camera-based capture. Experience with heterogeneous external systems also led to improved integrations, custom mappings and alternative data-capture routes, leaving residual dependencies where third-party systems provide limited interfaces.

Table 21. Maintaining digitally continuous inventory visibility

Interconnections within the thread

Inventory transparency in the TotalCtrl arrangement depends on continuity across both digital systems and the physical-to-digital inventory representation. Purchasing and supplier information can enter through structured integrations or alternative order-document capture routes, sales information can update outgoing movements, and the current physical-stock configuration combines shelf-level RFID with camera-based capture. Expiry-related visibility is produced through separate inventory information rather than RFID itself. These mechanisms become useful together when the resulting information remains sufficiently connected in the consolidated operational representation. This shows that data availability alone does not establish inventory transparency: information can exist upstream, in another system or in the physical environment while still being operationally weak if it becomes stale, loses relevant meaning or cannot be related to the current stock state.

The evolution of the inventory configuration illustrates how a design choice can change the conditions of transparency. Operational experience showed that RFID alone was not practical as an item-level tracing mechanism across all relevant product environments. Therefore, the configuration evolved towards shelf-level RFID combined with camera-based capture, a change TotalCtrl identified as important for achieving the required ease of use and inventory accuracy. This substantially reduces the burden of repeated manual stocktaking, while the resulting inventory representation still depends on the combined sensing configuration, product and movement information, and appropriate quality control. This operational experience provides a rationale for the combined configuration, while the case does not treat this as evidence of error-free sensing or universal inventory accuracy across customer settings.

Cross-system continuity also depends on relationships beyond TotalCtrl's direct control. TotalCtrl can configure mappings, synchronisation, and interfaces, but supplier, procurement, and sales systems determine whether relevant external data are available in a usable form, while operational and procurement users depend on the consolidated representation being current enough for action. Retaining the existing hospitality platform reduces the need to replace surrounding systems, but it also preserves dependencies on third-party interfaces and customer configuration. The fit-for-purpose condition is hence relational: continuity is produced through the interaction of TotalCtrl's integration design, external data provision, customer setup, and the operational uses for which the inventory representation is needed.

4.4.2. Low-burden automation with resilient data production

Analytical aspect	Application within the analytical thread
Focal purpose and object	Inventory and food-waste information that can be produced with low routine operational burden and sufficient reliability for hospitality use. The thread concerns how increasingly automated capture and integration reduce repetitive data-production work while maintaining the remaining technical, external-data, quality-control, and user-input conditions.
Stakeholders and relationships	**Kitchen staff, chefs, and other operational users** interact with physical stock and waste, but much less of the routine recording work is now carried out by them. They review inventory outputs and provide limited contextual inputs where needed, including limited contextual input during smart-scale use. **TotalCtrl** configures the sensing technologies, integrations, workflows, and quality-control arrangements, while managers and reporting actors depend on the resulting information.
Requirements	Capture of inventory and waste information should minimise repetitive manual work and fit ordinary hospitality workflows without undermining the completeness or consistency needed for operational use. Waste recording needs to be immediate and practical enough to sustain routine use while producing sufficiently reliable and consistently classified information for pattern identification, prevention, and reporting. Automation also needs appropriate customer setup, sensing performance, external data access, and quality-control arrangements.
Challenges	Earlier manual stocktaking and waste measurement created substantial time and transcription burdens. The more automated configuration reduces those burdens but still depends on the performance and setup of sensing technologies, supplier/procurement integrations and limited user inputs. External systems can differ in API availability and data structures, while customer environments may require different combinations of capture, integration, support, and fallback.
Tensions	Greater automation can remove substantial routine work and reduce exposure to human error, while leaving a smaller set of dependencies concentrated in sensing, external data provision, customer/system configuration, and quality control. Minimising user interaction supports low-burden operation, while the remaining inputs and review steps need to be sufficiently clear for reliable use. A common product architecture supports scaling, while customer-specific conditions can require different packages of automation, integration, and support.
Material configurations	The inventory configuration combines shelf-level RFID with camera-based capture. Supplier and purchasing information is consolidated through system integrations and alternative document-capture routes. The smart-scale configuration combines automated measurement and capture with limited user input to contextualise the waste record. Custom mappings, synchronisation, onboarding, support, and quality-control processes, including prompts or checks that retain a user review role where

	relevant, connect these mechanisms to the wider platform. Manual or alternative routes remain relevant where external systems cannot be integrated as intended.
Fit-for-purpose relationships	Automation can support inventory and waste transparency in routine operation when it substantially reduces recording burden, while the remaining sensing, classification, external data, and quality-control conditions are maintained. For food waste, recorded quantities, categories, and resulting trends can support pattern identification, prevention activity, and sustainability/reporting uses when capture remains sufficiently reliable and workable in ordinary use. Waste measurement does not by itself establish why waste occurred or demonstrate that subsequent changes in waste were caused solely by the digital arrangement.
Reconfigurations	The arrangement has moved from heavily manual inventory and waste recording towards progressively more automated capture. Manual stocktaking burden contributed to RFID-based experimentation and, after limitations in product-level RFID use became apparent, to a combined shelf-RFID and camera configuration. Demand for faster waste registration contributed to smart-scale capture, while pilot/user feedback informed interfaces and workflows. Integration experience also led to improved mappings and alternative routes for customers whose external systems could not be connected in the same way.

Table 22. Low-burden automation with resilient data production

Interconnections within the thread

Automation in the TotalCtrl arrangement changes how data-production responsibilities and dependencies are distributed rather than simply replacing manual tasks with technology. Earlier, operational staff carried out much of the repeated counting, weighing, and transcription work. Shelf-RFID/camera capture, system integrations, document capture, and smart-scale measurement shifted much of that burden into sensing, system configuration, and automated processing. This improves fit where low routine burden is required, but it also concentrates responsibility for reliable transparency in TotalCtrl's configuration, external data provision, sensing performance, and quality-control arrangements, while users retain a smaller role in review and contextual input. The material configuration and stakeholder roles thus change together as the arrangement becomes more automated.

The smart-scale configuration illustrates this redistribution particularly clearly. Automated measurement reduces operational burden, and the limited contextual input retained from users contributes to making the resulting waste record meaningful for prevention and reporting. Beyond automated capture, fit-for-purpose depends on the relationship among sensing, user input, classification, and quality-control practices. The same relationship also sets an interpretive boundary: recorded quantities and categories can reveal waste patterns without independently explaining why

waste occurred or establishing that subsequent outcome changes were caused by the digital arrangement. Pilot and user feedback can inform reconfiguration of the workflow, while evidence of operational fit remains distinct from evidence of measurement or classification accuracy.

The wider configuration shows that low-burden transparency can be achieved through substantial automation without assuming that every dependency disappears. External systems, customer setup, sensing performance, and quality-control routines remain consequential, while user involvement is increasingly concentrated in review, limited classification, and exception handling rather than repeated data entry. Implementation experience has also led TotalCtrl to combine and package components differently across customers and operational settings. Therefore, the practical question becomes which combination of capture, integration, support, and quality-control functions is sufficient for a particular customer, transparency purpose, and operating environment.

4.4.3. From visibility to operational action and reporting

Analytical aspect	Application within the analytical thread
Focal purpose and object	Integrated inventory, purchasing, and food-waste information that is sufficiently prioritised and interpretable for operational decisions, waste-management activities and managerial or sustainability reporting. The thread concerns how visibility is configured into role-relevant information for particular actions and reporting uses.
Stakeholders and relationships	**Kitchen staff and other operational users** benefit from reduced inventory-counting burden and review operational inventory outputs, while **F&B and procurement managers** use integrated purchasing, stock, price, and waste information for ordering and cost-related decisions. **Management, sustainability, and reporting actors** use aggregated information for performance monitoring and ESG/compliance purposes. **TotalCtrl** configures differentiated user roles, access levels, alerts, guidance, interfaces, and reports so that the same wider information environment can support different responsibilities without exposing all information to every user.
Requirements	Operational users need timely and sufficiently relevant information about conditions requiring attention, such as low stock, approaching expiry based on available shelf-life information, or recurring waste patterns. Procurement information needs to support ordering and cost-control decisions without overwhelming users with underlying data complexity. Waste and inventory information also need to be aggregated and presented in forms appropriate for management, sustainability, and reporting uses. Outputs and access should remain configurable to different roles and organisational contexts, particularly where purchasing or other commercially sensitive information is not relevant to all users.
Challenges	Integrated operational environments can generate more information than users can practically inspect or act upon. Different roles require different levels of detail and

	forms of interpretation, and information that is valuable for procurement or management may be irrelevant or sensitive for operational staff. Reporting requirements can also vary across organisations and contexts, making a single fixed presentation insufficient for every operational or ESG use. Recommendation functions should be interpreted in relation to the evidence available for their use rather than assumed to carry the same evidentiary weight as established operational outputs.
Tensions	Richer operational information can improve visibility while increasing cognitive burden. Role-based access can protect commercially sensitive information and reduce irrelevant detail, while requiring the configuration of appropriate information layers. Prioritised alerts and guidance can focus attention, but excessive status information can create noise if it is not connected to a user's role or required action. Common dashboards and reporting structures support reuse, whereas different organisational settings and reporting contexts require configuration.
Material configurations	The integrated TotalCtrl backend connects inventory, purchasing, supplier, sales/use, and waste information. Operational interfaces and dashboards present current conditions, while expiry-related and low-stock alerts prioritise items requiring attention. Waste analytics aggregate recorded waste into trends and patterns, and configurable managerial and ESG/compliance reports translate operational data into higher-level monitoring and reporting outputs. Differentiated user roles restrict or expose information according to operational relevance and sensitivity. The CoPilot functionality adds recommendations across purchasing, inventory and waste. Within this case analysis, evidence concerning its routine use is more limited than for the established operational outputs.
Fit-for-purpose relationships	Integrated operational information can support procurement, stock and waste-management decisions when the underlying data remain sufficiently current and meaningful, consequential conditions are prioritised for the intended user, and the resulting output fits the organisational role and use. Aggregated inventory and waste information can also support managerial and sustainability reporting when the relevant measures and reporting structure correspond to the intended purpose. More information is not automatically more useful: practical relevance depends on selecting and presenting information at a level connected to the user's responsibility and action.
Reconfigurations	User testing and feedback informed iterative changes to interfaces, workflows, and notification logic. The move towards faster waste measurement supported the smart-scale configuration, while external requirements to measure/report food waste and TotalCtrl's product roadmap also shaped this development. Technical experience with RFID, camera-based capture, and external integrations contributed to additional reconfiguration. As the arrangement expanded across customers and organisational settings, different combinations of integration, capture, support, access, and reporting were configured.

Table 23. From visibility to operational action and reporting

Interconnections within the thread

The value of integrated operational information depends partly on how effectively it directs attention for different users. TotalCtrl distinguishes between operational staff who benefit from automated inventory counting and review the resulting inventory reports, procurement actors who need purchasing, inventory, price, and waste information for cost and ordering decisions, and managerial or reporting users who require more aggregated information. In this regard, expiry and low-stock alerts, procurement information, and waste analytics do more than display underlying records: they configure which aspects of the available information become salient for particular operational purposes.

This relationship also connects actionability to organisational roles and access. TotalCtrl uses differentiated user roles so that operational users do not necessarily receive commercially sensitive information that is irrelevant to their tasks, and procurement or managerial users can access the information needed for their responsibilities. So, the fit-for-purpose relationship depends on both the quality of the underlying information and the relationship between the output, the intended user, and the action or reporting purpose. Therefore, information and alerts need to remain sufficiently connected to the role and action they are intended to support.

The configuration has been shaped by several interacting drivers over time. User testing and feedback informed adjustments to interfaces, workflows, and notification logic, while the move towards lower-burden waste capture supported the adoption of smart-scale functionality. At the same time, external requirements to measure and report food waste, TotalCtrl's product roadmap, and technical experience with inventory capture and integrations also influenced the direction of development. CoPilot adds a recommendation layer across purchasing, inventory, and waste, yet the available case evidence concerning its routine use is more limited than for the established operational outputs. Project reporting records improvements in inventory and food-waste management during pilot use, providing practical evidence of relevance without, by itself, establishing that the observed outcomes were caused solely by the digital system.

4.4.4. Findings and suggestions

Finding	Implication
Operational inventory transparency depends on digital continuity across physical stock and distributed information systems. Purchasing, supplier, sales/use, and physical inventory information can contribute to a common operational	The existence of relevant data within individual systems or physical environments does not, by itself, provide sufficient inventory visibility. TotalCtrl has substantially reduced earlier integration gaps, but the operational representation still depends on

representation when relevant data remain sufficiently current, meaningfully connected, and available across the different capture and integration pathways.	appropriate customer setup, third-party data availability, and the configured relationship between shelf-level RFID, camera-based capture, movement information, and expiry-related data.
Automation substantially reduces manual data-production burdens while leaving a smaller set of conditions consequential to transparency. Shelf-RFID and camera-based inventory capture, smart-scale measurement, OCR/document capture and system integrations remove much of the repetitive counting, transcription and waste-entry work. The resulting information still depends on sensing, external data provision, system configuration, quality control, and limited user inputs.	The TotalCtrl case shows that automation can genuinely remove substantial manual data-production work. Remaining dependencies are more concentrated and need to be considered in relation to the particular capture/integration configuration and customer environment.
Operational transparency becomes more useful when information is prioritised and represented in relation to specific roles and actions. Differentiated access, alerts, procurement information, waste analytics, and reporting outputs configure different aspects of the same wider information environment for operational, procurement, managerial, and sustainability purposes.	Increasing the amount of integrated information does not automatically increase its usefulness. Fit-for-purpose depends on the relationship between underlying data, the information brought to users' attention, the intended role, and the operational or reporting action it needs to support. Role-sensitive prioritisation can also prevent irrelevant or sensitive information from creating unnecessary noise.
The TotalCtrl arrangement has been materially reconfigured through the interplay of operational feedback, external requirements, technical experience, and product development priorities. The inventory configuration evolved from manual counting, through item-level RFID ambitions, towards combined shelf-RFID and camera-based capture; smart-scale functionality reduced the burden of waste recording; and interfaces, integrations, and information presentation were iteratively adapted.	The current configuration is not the result of a single linear improvement pathway. Different drivers have altered the conditions under which transparency is produced and used, while transfer across customers requires that the underlying functions be packaged and configured to fit different operational and technical environments.

Table 24. Main findings from the TotalCtrl case

Suggestion	Intended contribution	Conditions and trade-offs
Where continuity or data-quality problems are consequential to a user's action, continue to make relevant exceptions visible through selective, role-relevant quality-control signals rather	Preserve awareness of missing, stale or questionable information where it can change an operational decision, while aligning those signals with the existing role-	TotalCtrl already uses quality-control prompts and checks. Additional indicators should be introduced only where they add actionable information; excessive technical status information could create noise and

than increasing system-status visibility indiscriminately.	and action-oriented information design.	undermine the low-burden character of the arrangement.
As the arrangement scales, make customer-appropriate transparency configurations more explicit by distinguishing which capture, integration, support, and reporting elements are required, optional, or context-dependent across different customer settings.	Support more intentional packaging and communication of the solution across customers while preserving the functions needed for inventory continuity, low-burden data production, and action-oriented use.	Different customers may require different combinations of shelf-RFID/camera inventory capture, smart-scale functionality, procurement/POS integration, alternative document capture, support, and reporting. Configuration profiles should remain tied to the transparency purpose and customer conditions rather than becoming rigid product tiers that imply identical needs across contexts.
Continue to configure prioritised outputs, alerts, access levels and reports in relation to their intended user and operational or reporting action.	Strengthen the relationship between integrated visibility and practical use by surfacing consequential information at an appropriate level for operational staff, procurement/F&B managers, and managerial or sustainability-reporting users.	The current solution already applies differentiated roles and selective information. Further refinement should preserve this low-noise principle and avoid excessive tailoring or alerting that increases configuration and maintenance burden.

Table 25. Main suggestions for the TotalCtrl case

The TotalCtrl case shows how operational digital transparency depends on the interdependence of physical data capture, cross-system continuity, automation, selective human input, prioritised interfaces, and organisational use. The configuration has substantially reduced manual work in inventory and waste data production, while the remaining conditions are concentrated in sensing and system configuration, external data provision, quality control, and role-relevant user interaction. The case further shows that visibility becomes consequential through the way information is prioritised and configured for stock, procurement, waste management, and reporting purposes. Reconfiguration has been shaped by operational feedback, regulatory requirements, technical experience, product development priorities, and diverse customer contexts, making contextual configuration important for continued transfer and scaling.

4.5. Cross-Case Findings

The four case applications represent substantially different digital transparency arrangements. Agroknow focuses on professional food-risk intelligence, Agricolus on lot-level production and sustainability information, QualityChain on provenance and authenticity, and TotalCtrl on operational

inventory and food-waste transparency. They also differ in their principal users, information sources, technical components, and organisational settings. Despite this variation, the applications reveal several recurring considerations concerning how digital transparency becomes useful in practice. These similarities lead to recurring relationships between the information being represented, the wider arrangement through which it is produced and used, and the context in which that arrangement operates.

4.5.1. Matching digital information to its intended use and interpretive limits

Across the cases, the amount of information available and the presence of stronger technical verification did not, by themselves, determine what the resulting transparency could reasonably support. Agroknow's risk intelligence supported prioritisation, investigation, and preventive testing without directly establishing supplier non-compliance or the condition of a particular batch. Agricolus' sustainability information increased visibility while requiring appropriate selection and context for stronger interpretation, and operation duration could make farming effort visible and provide an input for further assessment without, by itself, establishing its value, efficiency, quality or sustainability. QualityChain distinguished blockchain-supported record integrity from the factual validity of substantive claims and from complete physical-chain provenance; verification of a protected product- or lot-linked mark similarly provided a particular assurance property without independently establishing the genuineness of the physical product carrying it. In TotalCtrl, operational information became useful when data distributed across physical stock and digital systems remained sufficiently current and meaningfully connected, and when outputs were prioritised in relation to the relevant organisational role and action.

These examples show that different forms of information and verification support different kinds of interpretation and use. Therefore, their outputs need to be understood in relation to what the underlying evidence and mechanisms actually establish. In this connection, risk modelling and model validation, record-integrity mechanisms, laboratory testing, contextual information, and operational quality controls perform different evidentiary, interpretive, or operational functions and should not be treated as interchangeable.

4.5.2. The relevant transparency configuration extends beyond technology

Across the four cases, consequential conditions affecting transparency were located in different parts of the wider arrangement rather than in the focal technology alone. In Agroknow, these included the availability and attribution of external evidence, the way that evidence was structured and modelled, validation and explanatory mechanisms, and the professional activities through which risk information

was interpreted and, where relevant, followed by testing or other verification. Agricolus' Production Lot depended on farm-level data production, farmer participation, agronomist support and data-quality practices, crop-specific structures and calculations, as well as the selection and presentation of information through the public QR layer.

QualityChain distributed different functions across contributing actors and technical and assurance mechanisms: supply-chain actors provided substantive information, QualityChain structured and registered it, blockchain mechanisms protected post-registration integrity, and additional evidence or certification could support particular substantive claims. Physical printing, packaging and capture conditions also became consequential for the protected-code configuration. In TotalCtrl, sensing, third-party data provision, system integrations, mappings, quality-control practices and limited user inputs operated together to maintain operational inventory and waste information. Automation removed substantial routine manual work while leaving a smaller set of dependencies concentrated in sensing, system configuration, external data provision and quality control.

As a result, the commonality across the cases is not that the same supporting components are always required. Instead, different combinations of data, actors, practices, validation mechanisms, and infrastructures become consequential depending on the transparency purpose and configuration. This also means that improving an individual technical component may not resolve limitations that originate elsewhere in the arrangement.

4.5.3. Transferability involves contextual adaptation

All four cases show that digital transparency arrangements can retain relatively stable components and adapt consequential elements to different settings. Agroknow retains a broad food-risk intelligence architecture while adapting data inputs and modelling configurations across commodities and configuring information for different professional and enterprise workflows. Agricolus uses a common Production Lot architecture for different crops while adapting crop-specific information structures; participation and support arrangements also remain consequential and may need to be configured differently as the arrangement scales. QualityChain retains a reusable Entity/Event traceability structure across different product chains while sector- and country-specific requirements continue to require contextual specification; its protected-code work further shows that physical printing, packaging and capture conditions can require adaptation even where the underlying cryptographic mechanism remains stable. TotalCtrl similarly retains a common platform, while capture mechanisms, system integrations, support, access, and reporting arrangements can be configured differently across customer environments.

Across the cases, reuse, extension, and scaling can involve retaining relatively stable technical or informational components while adapting elements that become consequential in different product, organisational, data, regulatory, or physical environments. Technology-context fit consequently involves not only assessing whether a technology is broadly suitable for a transparency purpose, but also identifying which parts of the wider arrangement can remain stable and which need to be reconfigured when the context changes.

Cross-case finding	Examples across the cases	Main implication
Digital information needs to match its intended use and interpretive limits.	Risk intelligence versus direct verification; sustainability and farming-effort visibility versus stronger interpretation; record integrity versus substantive truth, provenance coverage and physical authenticity; operational visibility versus currentness and role/action relevance.	Greater visibility or stronger technical verification does not automatically expand what the resulting information can reasonably support.
Consequential transparency conditions extend beyond the focal technology solution.	External evidence and professional verification; farmer participation and agronomic support; distributed information contribution and assurance; sensing, integration, quality control and user interaction.	Digital technologies need to be considered together with the wider data, actors, practices, validation mechanisms and infrastructures through which their transparency function is produced.
Transferability involves contextual adaptation rather than identical replication.	Commodity- and workflow-specific risk configurations; crop-specific Production Lots; supply-chain, regulatory and physical-deployment adaptations; customer-specific capture and integration arrangements.	Across cases, reuse and scaling can require retaining relatively stable components alongside context-specific configuration of consequential elements.

Table 26. Overview of the cross-case findings

Taken together, the case applications indicate that assessing or implementing digital technologies for transparency requires more than identifying their technical capabilities. Attention is also needed to what the resulting information is intended to support, what the wider configuration must provide for that information to remain meaningful and usable, and which consequential elements may need to change when the arrangement is transferred or extended to another context. These cross-case findings provide the empirical basis for evaluating how effectively the Digital Transparency Approach supported the analysis of different technology-provider settings.

5. Evaluation and Finalisation of the Digital Transparency Approach

This chapter presents the evaluation of the Digital Transparency Approach and considers its implications for the final version developed within WP3. The evaluation findings are first summarised, followed by the finalisation of the approach.

5.1. Evaluation of the Digital Transparency Approach

The SME technology provider evaluations assessed the credibility, relevance, usefulness, and perceived practical applicability of the researcher-applied case analyses and the Digital Transparency Approach. Across the cases, the feedback supported retaining the core analytical structure and its fit-for-purpose orientation, while also identifying a practical tension between analytical depth and ease of application. The evaluation also reinforced the importance of distinguishing documented or demonstrated capabilities from analytical interpretation and genuine uncertainty. Consequently, the evaluation informed finalisation primarily at the level of practical application. The analytical lenses were retained, and additional guidance was developed to help users frame an arrangement, examine it broadly, connect related issues into analytical threads, diagnose fit-for-purpose relationships, and prioritise appropriate responses. These refinements are presented in Section 5.2. As previously noted, the evaluation concerns the assessment of the researcher-applied analyses rather than a demonstrated independent application of the approach by the SMEs.

5.2. Practical Application of the Digital Transparency Approach

The Digital Transparency Approach is intended as an analytical and diagnostic tool for examining how a particular digital transparency arrangement is configured, whether it is fit for its intended use, where important dependencies, boundaries or unresolved issues remain, and where technical or organisational responses may be warranted. The analytical lenses presented in **Chapter 3** remain interconnected and are not intended to be applied as separate or strictly sequential stages. Insights generated through one lens may change how other aspects of the same arrangement are understood. Drawing on the four case applications and the practical-use considerations identified through the evaluation, the final approach is accompanied by five related activities to guide the analysis: **Frame, Examine, Connect, Diagnose, and Prioritise**. These activities do not modify the analytical structure of the approach. Instead, they provide a practical orientation for moving from a broad examination of an arrangement to a deeper relational analysis, diagnosis, and prioritisation.

Activity	Purpose	What to expect
Frame	Establish what digital transparency arrangement is being examined and the purposes against which it should be considered.	A concise understanding of the transparency object or information, intended purposes and users, relevant functions or sub-configurations, and initial boundaries of the focal arrangement.
Examine	Establish sufficiently broad coverage of how the current arrangement works through the interconnected analytical lenses.	An overview of the relevant stakeholders and their perspectives, capabilities and constraints; requirements and challenges; material configuration; validation and assurance; existing responses and unresolved issues; and significant design choices or reconfigurations.
Connect	Develop a manageable set of analytical threads that explain how important transparency purposes, functions or conditions are shaped through the wider configuration.	A set of central transparency questions and an understanding of the relationships and dependencies involved, including important differences in visibility, control, decision authority, burden, and resulting trade-offs.
Diagnose	Assess whether the resulting transparency is fit for its intended uses, for whom and under what conditions.	A concise diagnosis of strengths, relevant thresholds and conditions for fit-for-purpose use, dependencies, assurance and interpretive boundaries, uncertainties, and possible configuration needs.
Prioritise	Determine what warrants attention following the diagnosis and what kind of response is appropriate.	Priorities concerning what should be preserved, changed, clarified, monitored, or accepted, together with realistic technical, organisational or other response possibilities.

Table 27. Activities for the practical application of the digital transparency approach

5.2.1. Guiding questions for practical application

The following questions are intended as prompts and do not constitute a mandatory checklist. So, not every question requires the same depth in every application, and some questions may not be relevant to the specific context users analyse. The key is that users should first establish sufficiently broad coverage of the focal arrangement before narrowing their attention to technical problems or organisational priorities already considered important, since a broader examination may reveal dependencies, boundaries, or tensions that were not initially recognised.

Frame:

- What information, condition or object is intended to become transparent?
- For whom is this transparency intended, and what should it enable them to understand, assess or do?

- Are there distinct transparency purposes, outputs, functions or sub-configurations that need to be distinguished?
- What parts of the wider technology, organisation or supply chain need to be included for these purposes to be meaningfully examined?
- What can initially remain outside the focal arrangement?

The initial framing provides an analytical starting point instead of a permanent boundary. It can be reconsidered if subsequent analysis reveals consequential relationships extending beyond it.

Examine:

- Who produces, controls, configures, validates, uses, acts on or is represented by the relevant information?
- What responsibilities, capabilities, resources or constraints affect their ability to perform these roles or act on the resulting information?
- How do the relevant stakeholders judge whether the transparency is adequate, and which regulatory, professional, operational, contractual, commercial or other considerations shape those judgements?
- Are these perspectives obtained from the stakeholders themselves, or are some being assumed on their behalf?
- What requirements, challenges or tensions follow from these purposes, roles and perspectives, and how does the current arrangement respond to them?
- What remains unresolved or only partly addressed?
- How is the relevant information collected, processed, structured, connected, accessed, and presented?
- What functions do the important technical, informational, human and organisational elements perform in creating, shaping, validating or communicating the resulting transparency?
- Who can contribute, alter, correct, withhold, access or disclose relevant information, and under what conditions?
- What validation, evaluation or assurance evidence exists? What exactly does it establish or not establish?
- What significant design choices or previous reconfigurations help explain the current configuration?

Connect:

Candidate central transparency questions may begin to emerge while the arrangement is being framed and examined. Once sufficiently broad coverage has been established, users should determine which of these warrant deeper relational analysis. Rather than treating topics such as data quality, automation, participation, validation, integration or usability as separate issues by default, consider:

- How does an important transparency purpose, function or condition become sufficiently usable, credible, current, interpretable, verifiable or otherwise fit for its intended use?
- Which stakeholder requirements, expectations, and other relevant considerations shape that relationship?
- How do those requirements interact with data, technologies, interfaces, organisational practices, and design choices?
- What does an important element depend on elsewhere in the arrangement?
- Whose products, activities, behaviours or risks become more or less observable through the current configuration?
- Who shapes how information is represented, categorised or disclosed, and who can correct, contest or contextualise that representation?
- Who gains visibility, control or decision capacity, and who carries participation, data-production, assurance, disclosure or operational burdens?
- If one element changes, performs poorly or becomes unavailable, what else is affected?
- What benefits, trade-offs or new dependencies arise from important configuration choices or reconfigurations?

Diagnose:

- For each important, intended use, what level/form of information or evidence is adequate for the relevant stakeholder, and under what conditions?
- Are there explicit thresholds, criteria or decision rules for adequacy or action? If not, how is adequacy judged in practice?
- What does the resulting representation, calculation, score, traceability record or verification reasonably establish, and what stronger interpretation does it not support?
- Where are the most important dependencies, tensions, mismatches, limitations or interpretive boundaries?
- Could an apparent absence or problem reflect limited data availability, stakeholder participation or system coverage rather than the underlying reality?
- Which conclusions depend on assumptions or unresolved information that could materially change the diagnosis?

- Which limitations arise from the wider socio-technical configuration rather than from the focal technology itself?
- If the arrangement is transferred, scaled or extended, which elements have already demonstrated adaptability, and which would require new contextual specification?

Prioritise:

- Which findings matter most for the intended transparency purposes and uses?
- Which existing strengths should be preserved?
- Which findings require change, clarification or monitoring, and which limitations or boundaries can reasonably be accepted?
- Is the issue already addressed, partly addressed or included in an existing technical or organisational response or development roadmap?
- Who has the capacity or authority to influence it?
- What relationship or part of the configuration would actually need to change?
- What technical, organisational or other response is realistic?
- What benefit could it provide, and what trade-off, burden or new dependency could it introduce?
- Which responses warrant attention first, given their expected impact, feasibility, implementation effort or speed of execution, and other relevant implementation conditions?

5.2.2. Developing analytical threads

The transition from broad examination to deeper relational analysis is particularly important. The objective is not to create a separate analytical thread for every technology, stakeholder, requirement or challenge identified during the examination. Instead, related elements should be organised around a manageable set of central transparency questions. An analytical thread can be understood as a focused question concerning how an important transparency purpose, function, or condition becomes sufficiently usable, credible, current, interpretable, verifiable, or otherwise fit for a particular purpose, and what configuration, dependencies, and boundaries shape that relationship. This formulation does not need to be followed literally. **Its purpose is to distinguish an analytical thread from a general topic** such as data quality, automation, blockchain, participation or interoperability.

A useful analytical thread should connect an intended transparency purpose or use to the relevant stakeholders, requirements, challenges, and the technical and organisational configuration through which transparency is produced, as well as the conditions that affect whether it can support that use. **Each thread should be considered through all relevant analytical lenses**, although some lenses may

be more consequential to a specific thread than others. Relationships should not be manufactured simply to give every lens equal weight: the purpose is to check whether another part of the arrangement changes how the thread should be understood. This reflects how case analyses use threads to bring the interconnected lenses together without treating them as additional analytical lenses.

Candidate threads may begin to emerge during Frame and Examine, but they should be consolidated after sufficiently broad coverage has been established. As a practical guide, related topics can be grouped or separated according to whether they concern the same transparency relationship:

- **Combine candidate threads where they affect the same transparency outcome through substantially the same chain of dependencies.**
- **Keep them separate where they concern materially different transparency purposes, users, assurance functions, or operating and interpretive conditions.**

For example, in TotalCtrl, camera-based capture, RFID, OCR, manual fallback, training, and exception handling should not automatically become separate analytical threads. Several contribute to the broader relationship between low-burden data production, resilience, and data quality. However, maintaining digitally continuous inventory visibility raises a distinct relationship concerning whether information remains sufficiently connected and current across the operational arrangement. Therefore, the same component may contribute to more than one thread where it shapes different transparency relationships.

QualityChain illustrates the opposite situation. Blockchain-based provenance and protected-code authentication could both be labelled broadly as “verification,” but they establish different properties and depend on different conditions to support their respective assurance purposes. Blockchain-based traceability concerns the integrity and inspectability of recorded provenance information, whereas protected-code authentication concerns the protected mark and its physical deployment, copying or reuse, and connection to the physical product. Combining these into one verification thread would obscure an analytically important distinction.

Analytical threads should also be checked as a set. Together, they should provide reasonable coverage of the main transparency objectives and materially different functions within the focal arrangement, including important cross-cutting conditions. There is no required number of threads. A long list may indicate that several candidates concern closely related issues, while excessive consolidation may hide materially different purposes, users, assurance functions, or important contextual conditions.

5.2.3. Following relationships across the analytical lenses

The analytical value of a thread comes from following relationships across the digital transparency arrangement rather than describing its components in isolation. A data-quality problem, for example, may involve who produces or controls the data, the capabilities and burdens affecting data production, available manual or automated mechanisms, how missing information is handled, how the data are represented downstream, and what users can reasonably infer from them. Agricolus illustrates this reasoning. Farmer participation, recording practices, automated and manual capture mechanisms, agronomic support, and data completeness jointly shape lot-level transparency. The relevant question is thus not simply whether a technology can capture farm data, but how participation, technical capture, representation, disclosure, and downstream interpretation combine to support particular transparency purposes.

Validation and assurance should be examined in the same practical way. In Agroknow, supplier- and ingredient-risk intelligence can support prioritisation, investigation, and preventive action without directly establishing supplier non-compliance or the condition of a particular product batch. In QualityChain, the integrity of a blockchain record does not establish the factual truth or completeness of the information originally entered. When examining a similar issue, users should ask what the relevant mechanism or evidence actually establishes for the intended transparency purpose, what it does not establish, and whether additional actors, information or assurance processes are needed for the intended use.

Users should also check whether the current configuration creates important differences in visibility, control, or burden. For example, participation, data availability, integration, or capture capabilities may make some actors or conditions more visible than others, while choices concerning categories, models, permissions, or disclosure may affect who shapes the resulting representation and who carries additional data-production, scrutiny, or accountability burdens. Where such differences are consequential to the intended transparency purpose, they should be included in the relevant analytical thread even when the focal technology itself functions as intended.

5.2.4. Learning from significant reconfigurations

Reconfiguration should not be treated only as a question of future improvement or as evidence that an earlier configuration needed improvements. Changes may arise from evolving purposes, users, technologies, organisational conditions, scale, opportunities, or wider contextual developments, as well as from identified limitations. Examining important past or ongoing changes can help users

understand why the current arrangement has taken its present form and which conditions may remain consequential as it continues to develop.

Where a significant reconfiguration has occurred, users should consider what prompted the change; which technical, informational, organisational, or stakeholder-related elements changed; which requirement, limitation, opportunity, or contextual development was involved; and how the change affected the arrangement's intended use, dependencies, or trade-offs. For example, in Agricolus, operation-duration capture became part of the Production Lot configuration through Agriplug and related recording mechanisms. Examining this development helps clarify both the new visibility it creates and its interpretive boundary: recorded duration can make an aspect of farming activity visible and may provide input for further assessment without, by itself, establishing the value, efficiency, quality, or sustainability of that activity.

5.2.5. Sufficient depth over exhaustive depth

The approach does not require every possible relationship to receive equal analytical attention. Users should establish sufficiently broad coverage to avoid prematurely excluding important purposes, stakeholders, requirements, material components, or fit-for-purpose relationships, and then deepen the analytical threads that materially shape whether transparency can be produced and used as intended. The analysis should distinguish between **what is currently implemented and established, what belongs to an earlier configuration, what is planned or emerging, and what remains assumed or unresolved**. Available evidence of implementation and validation should be considered before a capability or condition is treated as unresolved. Intended functionality should similarly be distinguished from demonstrated or routine use, while stakeholder perspectives assumed by a technology provider should remain distinguishable from perspectives obtained directly from those stakeholders. These distinctions do not require formal research evidence coding in practical application, but they should remain explicit because they reduce the risk of treating expected capabilities, reported conditions, or interpretations as established properties of the arrangement. Where the focal arrangement is relatively simple or organisational capacity is limited, the same logic can be applied in a lighter form using the core questions, explicit evidence-status distinctions, and selective analytical depth rather than reproducing an in-depth analysis.

A review can be considered sufficiently developed when:

- The main intended use of transparency can be related to the configuration that supports it.
- The relevant stakeholder requirements, capabilities, and considerations affecting intended use are understood.

- The most important dependencies, thresholds, assurance boundaries, and uncertainties are explicit.
- The analytical threads collectively cover the important transparency functions without unnecessary duplication.
- The diagnosis can explain **why** the arrangement is or is not fit for the intended use of transparency rather than merely listing technical or organisational issues.

Where possible, bringing together technical and business or operational perspectives can strengthen the analysis, as different roles may have visibility into different parts of the same transparency configuration.

5.2.6. From diagnosis to prioritisation

Diagnosis does not imply that every limitation should be eliminated. Depending on the intended use and context, a finding may indicate a strength to preserve, a configuration to change, a boundary to clarify or accept, or a dependency to monitor. Before proposing a new response, users should also consider whether the issue is already addressed by the existing configuration, organisational practice, or development roadmap.

Where change is warranted, attention should first be directed to **which relationship or part of the configuration needs to change**, rather than immediately to a particular technical feature. Prioritised responses can then inform decisions on design, implementation, communication, or adaptation. Where these responses, or wider contextual changes, materially alter the transparency arrangement, the relevant framing or analytical relationships can be revisited. **Figure 1** summarises the practical navigation of the approach and the principal routes through which the analysis may be iterated.

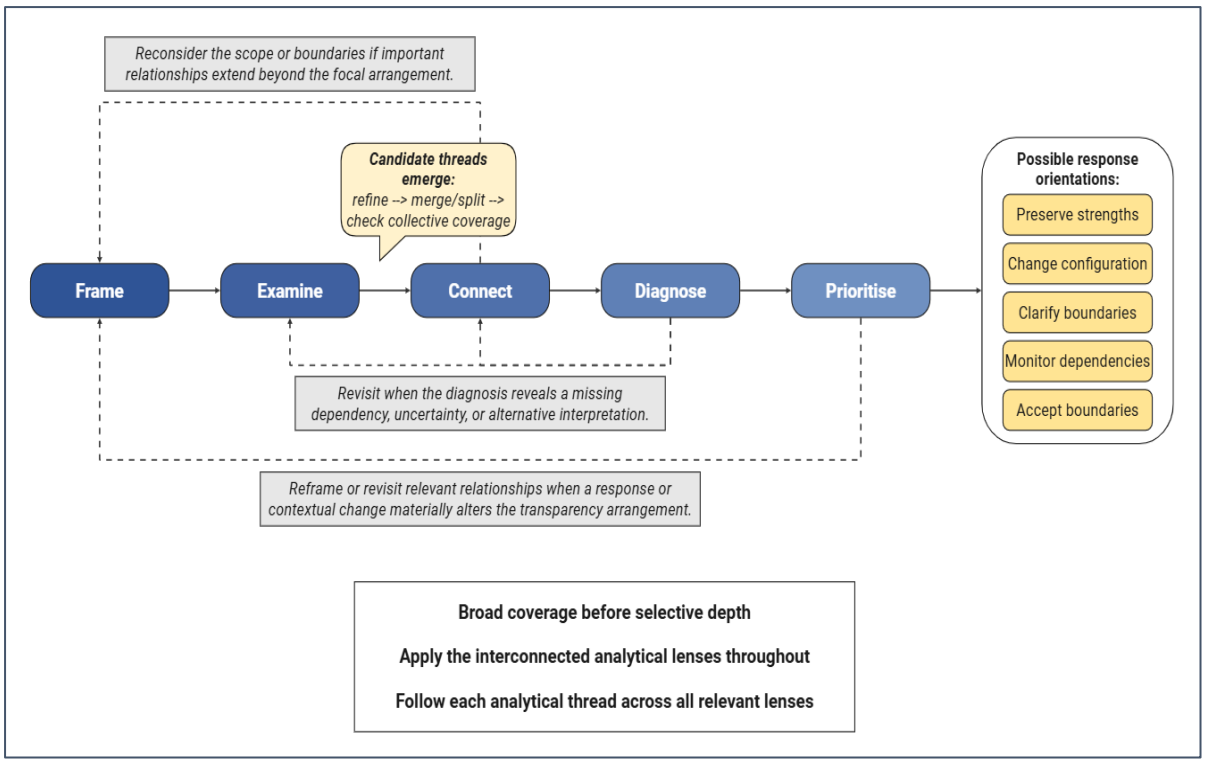

Figure 1. The practical navigation of the approach and the principal routes

6. Conclusion

WP3 set out to develop an approach to help stakeholders determine which digital technologies and methodologies are appropriate for specific transparency purposes in their FSC contexts. Building on the requirements, challenges, and technology-fit considerations identified earlier in WP3 work, this deliverable finalises and evaluates that work by treating technology suitability as a context-dependent socio-technical question. The resulting Digital Transparency Approach examines whether particular combinations of information, technologies, stakeholder relationships, and organisational practices are fit for a defined transparency purpose, what conditions that fit depend on, and where adaptation or reconfiguration may be required.

The approach was applied across four substantially different TITAN SME technology-provider cases covering professional food-risk intelligence, lot-level agricultural transparency, product provenance and authenticity, and hospitality inventory and food-waste transparency. Three cross-case findings were particularly important. First, making more information available or applying stronger technical verification does not automatically enhance what the resulting transparency can reasonably support, so different forms of information and assurance should be interpreted in relation to what the underlying evidence and mechanisms actually establish. Second, consequential transparency conditions frequently extend beyond the focal technology to include data availability and quality,

stakeholder participation, validation, system integration, professional interpretation, and organisational practices. Third, transfer and scaling involve contextual adaptation: relatively stable technical or informational components may be reused, while other consequential elements may need to be reconfigured as product, organisational, data, regulatory, or physical conditions change.

The evaluation supported retaining the core analytical structure and informed the practical guidance accompanying the final approach. Accordingly, the final version complements the interconnected analytical lenses with guidance for framing an arrangement, examining it broadly, connecting related issues into analytical threads, diagnosing fit-for-purpose relationships, and prioritising appropriate responses.

The evidence presented in this deliverable remains context sensitive. The four cases are not intended to represent all digital technologies or FSC contexts, and the detailed analyses and feedback received are primarily technology-provider-centred. The evaluation also concerns SMEs' assessment of researcher-applied case analyses rather than demonstrated independent application of the approach. Within these boundaries, D3.6 provides an approach for examining digital transparency as a configurable socio-technical arrangement and for supporting more context-sensitive decisions concerning technology design, implementation, and adaptation.

7. Policy Brief: Recommendations for SMEs, Investors, and Policymakers

Digital transparency arrangements create more value when technology solutions are matched to clear transparency purposes, social and organisational considerations, credible information, sufficient assurance, and workable implementation conditions. The following recommendations support SMEs developing or adopting these solutions, investors assessing their potential, and policymakers enabling their responsible deployment and scaling.

Recommendations	For SMEs	For investors	For policymakers
Choose technologies for the transparency function and context, not for the technology itself.	Define the transparency need, stakeholders, and intended use before selecting technologies.	Check that the technology addresses a clear transparency need and fits the intended context.	Support outcome-oriented, technology-neutral approaches rather than prescribing particular technologies.
Make digital transparency useful, not simply more visible.	Design outputs around what users need to understand or act on;	Assess whether the solution turns data into useful information for its intended users.	Avoid equating stronger transparency with more data or universal disclosure.

	avoid unnecessary information overload.		
Be precise about what the technology actually establishes.	Keep claims aligned with what the technology and evidence can genuinely support.	Scrutinise claims about traceability, prediction, verification, authenticity, and assurance.	Require claims and reporting to be proportionate to demonstrated capabilities and evidence.
Build data quality and validation into the transparency arrangement.	Make data origin, quality checks, correction, and validation part of the solution design and supporting practices.	Examine whether reliable outputs depend on data or validation conditions outside the SME's control.	Encourage data quality and assurance mechanisms alongside investment in data-processing technologies.
Design interoperability around meaning as well as connectivity.	Address identifiers, formats and semantics alongside APIs and system integration; reuse existing data where possible.	Assess how much customer-specific data mapping and integration is required for deployment.	Support technical and semantic interoperability and reduce fragmented or duplicative data requirements.
Build secure and selective data sharing into the architecture.	Use appropriate access controls, privacy, security, and confidentiality mechanisms instead of assuming all data should be open.	Examine whether data access, ownership, and confidentiality arrangements can support sustainable deployment.	Enable trusted, proportionate data sharing while protecting sensitive information.
Make digital technologies usable for the actors expected to operate them.	Minimise unnecessary complexity and provide suitable onboarding, training, and support.	Consider whether user skills, infrastructure, or resource constraints could limit adoption.	Support digital capacity, infrastructure, and technical assistance where adoption barriers remain.
Account for the full cost of technology deployment.	Include integration, configuration, data preparation, validation, onboarding, maintenance, and support in planning and pricing.	Assess total deployment and support economics, not only software or hardware costs.	Recognise enabling and implementation activities as legitimate costs in digitalisation support programmes.
Automate where it adds value, but design for quality	Automate repetitive work while retaining appropriate quality	Look for hidden manual work and dependencies behind automation claims.	Encourage automation that improves efficiency without overlooking

control, exceptions, and fallback.	control, correction, and fallback mechanisms.		resilience, oversight, and exception handling.
Distinguish demonstrated technical capability from deployment readiness.	Communicate clearly what has been prototyped, tested, piloted, and routinely deployed.	Separate technical promise from evidence of operational and commercial readiness.	Evaluate funded technologies beyond successful demonstrations or pilot completion.
Design technologies for adaptation as well as replication.	Identify what can remain standard and what needs configuration across products, customers, and contexts.	Assess whether adaptation is manageable and repeatable as the business scales.	Allow and support justified contextual adaptation when technologies are transferred or scaled.
Demonstrate the value created by digital transparency, not only compliance with requirements.	Show how the solution creates operational, risk, efficiency, assurance, or market value for users.	Test whether the value proposition remains compelling beyond regulatory pressure or project funding.	Encourage digital transparency solutions that combine compliance with meaningful operational and societal value.

Table 28. Recommendations for SMEs, investors, and policymakers

Choose technologies for the transparency function and context, not for the technology itself:

Digital technologies can create different forms of transparency depending on what they are used for and how they are configured. Therefore, the starting point should be the transparency purpose, intended users, required information, and relevant context, followed by selection of the technology (or combination of technologies) that can realistically support those needs.

Make digital transparency useful, not simply more visible:

Digitalisation can substantially increase the amount of information that becomes available, but greater visibility does not automatically make information more useful or interpretable. Digital outputs should be selected, contextualised, and presented according to the intended users and the decisions or actions they are expected to support.

Be precise about what the technology actually establishes:

Different technologies and validation mechanisms provide different types of evidence and assurance. Prediction, traceability, record integrity, authentication, and substantive verification should not be treated as equivalent, and claims about a digital solution should remain within the boundaries of what its data and mechanisms can reasonably demonstrate.

Build data quality and validation into the transparency arrangement:

Reliable digital transparency depends on the information entering the system as well as on the technologies used to process, analyse, store, or communicate it. Solutions should thus consider data origin, completeness, accuracy, attribution, correction, and validation, including dependencies on external data sources, sensors, or human contributions.

Design interoperability around meaning as well as connectivity:

Connecting digital systems is only one part of interoperability. Information also needs sufficiently compatible identifiers, formats, definitions, and semantic structures, so that it retains its meaning when exchanged between organisations and systems. Where appropriate, existing information should also be reusable rather than repeatedly collected into disconnected systems.

Build secure and selective data sharing into the architecture:

Creating digital transparency does not require making all available information accessible to everyone. Technologies should support appropriate levels of access while protecting privacy, confidentiality, ownership, and commercially sensitive information through suitable security and access-control mechanisms.

Make digital technologies usable for the actors expected to operate them:

A technically capable transparency arrangement may still fail to create useful transparency when the people expected to operate it face limitations in digital skills, infrastructure, available time or resources. Interfaces, data-entry requirements and deployment workflows should avoid unnecessary complexity, with appropriate onboarding, training, and technical support provided where needed.

Account for the full cost of technology deployment:

The cost of digital transparency extends beyond the purchase or development of software, hardware, or licenses. Integration, configuration, data preparation, onboarding, validation, maintenance, training, and technical support can materially affect the feasibility and sustainability of a technology solution and should be considered from the outset.

Automate where it adds value, but design for quality control, exceptions and fallback:

Automation can substantially reduce repetitive data production, monitoring, and reporting work, but real operating environments can still involve missing information, technical failures, unusual cases, and quality-control needs. For this reason, robust digital transparency arrangements should retain

appropriate mechanisms for checking, correction, selective user input, or fallback where these remain necessary.

Distinguish demonstrated technical capability from broader deployment readiness:

A successful technical test, prototype, pilot application, or user evaluation does not necessarily establish that all conditions for routine deployment or scaling have been demonstrated. So, digital transparency arrangements should clearly communicate what has actually been tested, under which conditions, and which dependencies remain relevant for broader operational or commercial deployment.

Design technologies for adaptation as well as replication:

Digital transparency arrangements may retain relatively stable technical or informational components while requiring changes to data structures, integrations, interfaces, validation arrangements, or physical deployment as they move between products, customers, or environments. Scalability should include the capacity for manageable contextual adaptation rather than assuming that a successful configuration can simply be reproduced unchanged.

Demonstrate the value created by digital transparency, not only compliance with requirements:

Compliance is an important driver of digital transparency, but technologies can also support risk management, operational efficiency, decision-making, traceability, food safety, assurance, and communication. Therefore, a digital transparency arrangement should make clear what useful outcome it enables and why that value is sufficient to support continued adoption and investment.

These recommendations highlight that credible digital transparency depends not only on what a technology can do, but on how it is configured, supported, and used within specific FSC contexts. Digital technologies can create substantial value for transparency when approached from a socio-technical perspective with attention to the capacity to adapt as contexts change. SMEs, investors, and policymakers can use these considerations to support more informed decisions about the development, investment, adoption, and scaling of digital transparency arrangements.

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Appendix

This inventory consolidates transparency-relevant digital technologies and methodologies identified across the four SME cases. The clusters are case-derived analytical groupings rather than a universal taxonomy. The function is described in relation to the specific context of each inventory item, and the boundary indicates what each item can support and what it does not, by itself, establish.

Cluster	Digital technologies & methodologies	Function	Context	Boundary
Geospatial mapping	GIS; georeferenced field mapping; field geometry; machinery routes; yield maps.	Links information to the location.	Field monitoring, machinery tracking and spatial comparison.	Supports spatial association and targeting. Accuracy depends on correct georeferencing and underlying data; location alone does not establish field condition or cause.
Remote sensing	Satellite imagery; Sentinel-2/Copernicus; vegetation indices; multi-temporal analysis.	Derives spatial indicators of crop condition and change.	Distributed field monitoring where usable imagery is available.	Supports indicators such as vigour, water stress and chlorophyll. Cloud cover can prevent observation, and detected patterns still require interpretation or field checking.
Agricultural observation & sensing	Weather and virtual weather stations; field/machinery sensors; automatic traps; AgriPlug; location-based machinery tracking; crop scouting.	Captures field, environmental and operational observations.	Crop monitoring, treatment timing and field/machinery activity.	Supports observation of configured variables and events. Precision depends on observation method and conditions; measured variables do not alone establish wider quality or sustainability.
RFID	Shelf-level RFID tags; antennae/readers; RFID-enabled counting.	Supports automated shelf-location reference and stock counting.	Inventory environments where tags/readers can be deployed.	Supports lower-burden inventory capture. In the demonstrated shelf configuration, RFID does not itself identify individual products or establish expiry, provenance or condition.

Smart-scale measurement	Smart scales; digital weight capture.	Automates measurement of food-waste quantity.	Food-waste monitoring integrated into disposal workflows.	Supports direct weight capture with reduced manual entry. Weight alone does not identify what was wasted, why it was wasted or its provenance.
Computer vision	AI cameras; item/location recognition; camera/AR-supported waste recognition.	Recognises or classifies physical items visually.	Inventory and waste processes where visual recognition can complement other capture.	Supports automated recognition and positioning. Performance depends on imaging/configuration, and images alone do not establish attributes such as provenance or expiry.
External-data acquisition	Web scraping/crawling; automated authority monitoring; social-media extraction.	Collects external information at scale.	Fragmented, multilingual and distributed online sources.	Broadens accessible information beyond feasible manual monitoring. It does not guarantee complete coverage, consistent formats, relevance, attribution or source credibility.
Automated extraction & entry	NLP; ML text classification; OCR.	Converts documents/text or assists inputs into structured data.	Document-, text- and data-entry-intensive workflows.	Reduces manual structuring effort and can improve consistency. It does not establish source truth or guarantee error-free extraction/entry, so validation remains important.
Standard identifiers & links	Unique lot codes; QR codes; barcodes; GS1 Digital Link.	Associates physical products/lots with digital identities or information.	Product/lot handoffs and downstream or consumer access.	Supports identification and low-friction access to associated information. An identifier or link does not itself authenticate the physical product or establish claim accuracy.
Digital record systems	Inventory/order/delivery records; farm-operation records; waste records;	Maintains current and historical digital records.	Recurring operations or risk-monitoring processes	Supports continuity, retrieval and historical comparison. Records reflect only what is captured and maintained; they do not by

	incident/recall and supplier records.		requiring retained histories.	themselves establish completeness, physical accuracy or end-to-end traceability.
Semantic harmonisation	Ontologies; controlled vocabularies; closed domains; crop-specific structures; semantic resources; harmonisation/normalisation.	Aligns terminology and representations across heterogeneous data.	Multi-source, multi-user or cross-system information.	Supports consistent interpretation and comparability. It does not itself provide connectivity or validate source data, and migration between semantic structures may require contextual mapping.
Traceability data models	Production Lots; Entity/Event model; actor/location/product/event structures; input-output lot relationships.	Structures provenance, transformations, and product histories.	Lot- and event-level traceability across supply-chain stages.	Supports reconstruction of connected recorded histories. It does not prove the truth of entries or that every relevant stage of the physical journey has been captured.
Data-quality controls	Data-quality assessment; cross-source validation; completeness/consistency checks; agronomist review/correction; quality-control prompts/checks.	Identifies and addresses unreliable, missing or inconsistent data.	Data feeding traceability, indicators or predictive analysis.	Improves the reliability of digital records and downstream analysis. It does not independently verify that every reported event or substantive claim occurred as recorded.
System integration	REST APIs; enterprise quality-management integration; Agrirouter; supplier/POS/procurement integrations; schema mapping; synchronisation; portal/email capture.	Moves and synchronises information across systems.	Cross-organisational or multi-system workflows.	Supports continuity and reuse without replacing surrounding systems. Connectivity alone does not ensure common meaning or data quality and remains dependent on external interfaces and data availability.

Privacy-preserving data use	Anonymisation.	Enables use or analysis of sensitive data with reduced raw-data exposure.	Private cross-organisational data where direct pooling creates confidentiality /liability concerns.	Supports some uses of private data without unrestricted raw-data exchange. It does not remove governance, liability or trust requirements, and stronger protection can constrain explainability.
Predictive modelling	Agronomic forecasts; multi-factor food-risk forecasting; feature extraction; machine-learning/time-series prediction; data-eligibility criteria; performance validation; predictive procurement.	Produces forward-looking estimates of risks, conditions or needs.	Data-sufficient settings where forecasts can inform action.	Supports anticipation, early warning and prioritisation. Predictions remain data- and model-dependent and do not establish that a forecast event will occur or that a specific product/supplier is unsafe.
Prescriptive decision support	DSS; precision-farming prescription; prescription/variable-rate maps; ML prescriptive algorithms; Copilot/recommendations; smart shopping guidance.	Translates data and analysis into suggested actions.	Farm-management, purchasing, inventory and waste decisions.	Supports selection and prioritisation of possible actions. Recommendations do not prove the optimal action or guarantee the intended operational, sustainability or risk outcome.
Indicators & derived metrics	Supplier-risk/severity scores; sustainability indicators; working-time/yield metrics; inventory/cost metrics; shelf-life/expiry estimates; waste/ESG metrics; QR/page analytics.	Converts records into scores, estimates or indicators.	Monitoring, comparison, prioritisation and reporting.	Supports summarisation and comparison. Outputs inherit input quality, evidence availability and calculation assumptions and should not automatically be treated as direct measures of the wider construct represented.

Interfaces, dashboards & reporting	Risk/prediction dashboards; operational interfaces; alerts/reports; sustainability, waste and ESG dashboards; consumer landing pages; explainability/context panels.	Presents and prioritises information for particular users and purposes.	Operational, professional, managerial and public-facing use.	Supports access, interpretation and communication. Presentation does not improve underlying evidence quality, and information can still be misunderstood without adequate context, benchmarks or uncertainty information.
Blockchain & smart contracts	Public blockchain; notarisation; Ethereum/EVM networks; smart contracts; event logs; transaction records; integrity hashes; anchoring.	Provides tamper-evident registration and inspectable integrity evidence.	Traceability where post-registration integrity and auditability are valuable.	Supports evidence that a record was registered and not subsequently altered. It does not establish truth at entry, complete participation or that recorded events fully represent the physical product journey.
Digital signatures	Cryptographic signatures; signed payloads; product/lot-linked signed data; blockchain-linked time references.	Supports integrity/authenticity checking of signed digital content.	Digital records or protected identifiers requiring cryptographic assurance.	Supports verification of signed-payload integrity/authenticity. It does not establish the factual truth of the associated claim or, by itself, the genuineness of the physical product.
Steganographic anti-counterfeiting	Hidden/steganographic marks; cryptographic signatures; artistic QR generation; error-correction and recovery mechanisms; dedicated protected-code verification; print/capture design guidance.	Adds a covert, recoverable authentication layer to QR codes.	Packaging/labels requiring stronger authentication under workable print and capture conditions.	Supports recovery and verification of a protected signed mark while preserving ordinary QR use. Verification does not by itself establish physical-product genuineness or general resistance to copying or reuse, and performance remains dependent on print, capture and deployment conditions.

Access control & selective sharing	User roles; permissions; access levels; restricted information layers; selective visibility/sharing.	Controls which information is visible to different users.	Multi-user systems containing sensitive or role-specific information.	Supports differentiated disclosure according to role and need. It does not improve data accuracy or establish that the chosen disclosure level is sufficient, fair or appropriate for every transparency purpose.
Resilient data capture	Automatic/manual dual-source capture; manual fallback; alternative capture routes.	Maintains data continuity when primary capture, connectivity or integration fails.	Unreliable connectivity/devices or heterogeneous external systems.	Supports continuity and reduces dependence on a single capture route. It does not eliminate loss or error, while fallback routes can reintroduce manual burden and input error.

Table 29. Inventory of case-derived digital technologies and methodologies for transparency

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