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La sicurezza alimentare e il ruolo dell'innovazione nell'accelerazione dei processi di trasformazione dei sistemi alimentari. *

Dr. Francesco D'Ausilio

Agricoltori, allevatori, trasformatori, confezionatori, trasportatori, distributori, rivenditori e consumatori, garantiscono il **funzionamento del sistema alimentare**. Le filiere producono, trasformano e distribuiscono ogni giorno una vasta gamma di prodotti alimentari a miliardi di consumatori in tutto il mondo e garantiscono il sostentamento a centinaia di milioni di persone con prodotti agricoli freschi e alimenti trasformati. La carenza di cibo, le perdite pre e post-raccolta, l'uso non sostenibile di terra, acqua ed energia, lo spreco alimentare, le frodi alimentari, le pratiche commerciali non etiche, il lavoro giusto e i cambiamenti climatici, **costituiscono tutte sfide con le quali le catene di approvvigionamento si misurano quotidianamente.**

L'innovazione digitale è decisiva nella gestione delle filiere alimentari. Sostenibilità, qualità e sicurezza sono temi al contempo, enormi e complessi. Ogni scelta, in tal senso, comporta un costo finanziario e organizzativo. Il rispetto di standard, la conoscenza tra gli attori e l'interconnessione nella catena di approvvigionamento alimentare multilivello. La compliance delle procedure e dei sistemi rispetto alla normativa che cambia frequentemente. **Sono questi i titoli di un'impresa che richiede cambiamenti sistemici.**

Siamo davanti ad un passaggio cruciale nel dibattito sul futuro dell'agricoltura e del agri-industria europea. **La trasformazione che sta attraversando l'agricoltura** europea vede al centro la transizione verso un modello più sostenibile ed equo, affrontando sfide come i cambiamenti climatici, l'aumento dei costi di produzione e la necessità di modernizzazione. Clima, produttività dell'agricoltura, competitività delle imprese, redditi degli agricoltori e prezzi dei prodotti agricoli sono soli i titoli. Le scelte, ad esempio sulle regole commerciali e gli strumenti di sostegno al reddito a partire dalla **Pac post-2027**, costituiranno il banco di prova. La transizione è complessa e gravida di tensioni. Il dibattito oltremodo polarizzato sull'impatto della transizione ecologica e digitale in agricoltura degli ultimi anni è lì a testimoniare. Il **Dialogo Strategico sul futuro dell'agricoltura UE**, promosso nel 2024 dalla Commissione, ha segnato almeno a livello di metodo,

una novità positiva per una rinnovata collaborazione tra agricoltori, imprese, industria e società civile. Ne misureremo gli effetti nei prossimi anni.

Qui recita un ruolo **l'innovazione digitale**. Nel 2017, il *World Economic Forum* ha pubblicato il rapporto (*Innovation with a Purpose: The Role of Technology Innovation in Accelerating Food Systems Transformation*), che identificava le dodici tecnologie con il potenziale di migliorare i sistemi alimentari. La tracciabilità era una di queste. Siamo consapevoli di quanto essa non costituisca una soluzione miracolosa, ma presenti promesse distintive nell'aiutare a guidare la trasformazione dei sistemi alimentari. Ha il potenziale di rafforzare l'inclusività e di dare potere ai produttori su piccola scala, assicurare loro una maggiore visibilità sul mercato e accesso a nuovi servizi e risorse. Ossia **la capacità di trasformare dati complessi in decisioni concrete**: irrigare quando serve, prevedere stress climatici, ridurre sprechi, migliorare resilienza e fornire informazioni lungo tutta la filiera. **Gli strumenti tecnologici, costituiscono gli abilitatori della transizione ecologica e digitale in agricoltura e nell'agroalimentare**. Abilitatori che trasformano l'incertezza in informazione operativa, migliorando la capacità degli agroecosistemi di anticipare, assorbire e adattarsi agli shock, e contribuendo alla costruzione di **un sistema alimentare certamente più stabile e resiliente**.

La **transizione digitale** in agricoltura non è certamente giro di valzer. Ci riferiamo ad un mercato, quello dell'agricoltura 4.0, che ha in Italia un valore rilevante (2.3 miliardi di euro). Le tendenze sulla dimensione della digitalizzazione in Italia, tracciate dall'*Osservatorio Smart AgriFood del Politecnico di Milano*, lo confermano. Ne cito alcuni: il rallentamento del 2024 del mercato dell'agricoltura 4.0 dovuto alla riduzione degli **incentivi pubblici**, alla flessione dei **redditi agricoli** e agli **investimenti** già realizzati negli anni precedenti; il tasso di **maturità tecnologica** stesse delle imprese, relativamente ancora troppo basso; infine la propensione agli investimenti e all'adozione stessa delle tecnologie ancora troppo ancorato alla dimensione dell'azienda.

Dall'analisi dei dati emergono alcuni segnali incoraggianti. Penso all'aumento della domanda di **soluzioni digitali da parte delle imprese**, con un aumento degli investimenti in software gestionali per le aziende agricole (FMIS-Facilities Management Information System per il 13,5% del totale), ai Sistemi di Supporto alle Decisioni (Dss, per il 9,5%) sino agli strumenti di **monitoraggio e mappatura** di colture e suoli (rispettivamente 9% ciascuno); penso alla generale crescita in **consapevolezza** da parte degli agricoltori nei confronti del paradigma digitale, mossa dall'interesse di poter migliorare la propria **capacità previsionale**, nonché dal **controllo** e la **gestione** della propria azienda. Solo al **terzo posto c'è** la difesa del campo; infine penso, all'aumento della superficie coltivata con tecnologie digitali in Italia che è cresciuta seppur lievemente, passando **dal 9% nel 2023 al 9,5% nel 2024**.

Ma non è tutto. L'attenzione registrata all'evoluzione dell'**intelligenza artificiale** nel settore è importante, con una **crescita del 22%** nel numero di startup che propongono soluzioni basate su AI e machine learning. Infatti, circa **un terzo delle nuove soluzioni di agricoltura 4.0 in Italia** si basano su queste tecnologie, applicate alla gestione delle attività in campo, alla protezione delle colture e all'ottimizzazione dell'uso di risorse come acqua e agro farmaci. Ma anche il **carbon farming** (mi riferisco in particolare alle pratiche per ridurre emissioni e aumentare lo stoccaggio di carbonio nel suolo e vegetazione, con modelli di business che premiano chi adotta queste pratiche), segnano la crescita di un mercato sebbene prevalentemente volontario, concentrate su alcune coltivazioni specifiche e nella zootecnia, dove **i due terzi dei progetti finanziati utilizzano strumenti digitali**. Infine, anche nella **trasformazione alimentare**, l'intelligenza artificiale sta giocando un ruolo chiave, soprattutto nel monitoraggio della sostenibilità e della qualità dei prodotti, con particolare attenzione alla protezione delle **certificazioni di qualità come le Dop e le Igp**, che come evidenziato nel *Rapporto ISMEA 2025*, raggiunge un giro d'affari di oltre 20 miliardi di euro nel 2024, contribuendo per il 19% al fatturato complessivo dell'agroalimentare nazionale.

I benefici attesi dalla digitalizzazione sulla sicurezza alimentare sono rilevanti. **Efficienza operativa**: riduzione sprechi, time-to-market più rapido. **Tracciabilità e compliance**: risposta veloce a richiami, riduzione rischi legali. **Brand trust e sostenibilità**: trasparenza su origine e impatto ambientale. **Tasso positivo di ritorno dell'investimento (ROI)**: atteso grazie alla riduzione dei costi operativi e all'ottimizzazione processi.

I trend chiave in materia di adozione tecnologica della supply chain sono estremamente interessanti, e sono caratterizzati dall'adozione di tecnologie **blockchain** utilizzata per tracciabilità end-to-end, sicurezza delle transazioni e conformità ESG, **IoT** per il monitoraggio in tempo reale (temperatura, posizione, condizioni

ambientali) e **RFID** per la tracciabilità low cost. In generale, i trend sono caratterizzati da un crescente uso di **AI, digital twin o gemello digitale** per *simulare e ottimizzare* sistemi complessi con facilità, rivoluzionando il **Product Lifecycle Management (PLM)** della filiera con nuovi livelli *di* integrazione, sincronizzazione *e* collaborazione.

Gli **ostacoli e le componenti critiche** su cui è necessario intervenire per tentare di accelerare la transizione non sono secondari. I costi di **adozione** di nuove tecnologie, la **necessità di competenze tecniche specifiche** per l'utilizzo e la manutenzione, il **rischio di creare un divario digitale** tra le grandi aziende e le piccole, lasciando queste ultime indietro. Ma anche la **necessità di infrastrutture di rete**, soprattutto in aree rurali, e la **scarsa interoperabilità tra diverse piattaforme e macchinari**, che rende difficile l'integrazione dei sistemi. La **governance dei dati**, attraverso la condivisione di informazioni sensibili lungo la filiera che richiede standard comuni, appunto una interoperabilità tra sistemi e solide garanzie di sicurezza e privacy. Lo sviluppo di **infrastrutture dati** attraverso un accesso stabile a dati satellitari, reti IoT e stazioni meteo automatiche. La disponibilità di **data hub territoriali** per condividere informazioni e strumenti analitici tra agricoltori, consorzi e ricercatori. Solo rimuovendo questi ostacoli **la tracciabilità e interoperabilità saranno realmente efficaci**, solo se supportate da protocolli condivisi, regole chiare su proprietà e accesso ai dati e adeguate garanzie di sicurezza, potranno dispiegare il loro potenziale di sviluppo.

La strada per implementare **sistemi di tracciabilità end-to-end abilitati dalla tecnologia** nelle catene del valore alimentare, non né scontata né breve. **Le implicazioni commerciali** relative ai benefici della tracciabilità, a partire da un più efficace accesso ai mercati internazionali, dove la tracciabilità è requisito chiave ad esempio è un fattore su cui è necessario intervenire. Mercati internazionali dove il 54% delle aziende italiane fatica a espandersi a cause delle barriere digitali e normative, e dove una mancata conformità, costituisce un serio ostacolo alle opportunità di export; tra gli ulteriori benefici della tracciabilità non possiamo non citare la rimozione delle **barriere ai flussi di dati**: dove privacy e localizzazione molto spesso complicano le operazioni globali delle imprese; altresì, cito l'adozione di **nuovi modelli di business** che includono l'**omnicanalità** (integrazione tra canali online e fisici), i **marketplace** (piattaforme che connettono acquirenti e venditori) e il **packaging sostenibile** (imballaggi ecologici che minimizzano l'impatto ambientale). Esperienze, canali e prodotti che rispondono alle crescenti domande dei consumatori; e da ultimo, cito l'**effetto su brand e vendite determinato dalla tracciabilità dei prodotti**: sappiamo che il 70% dei consumatori è più propenso ad acquistare prodotti tracciabili.

La supply chain nel settore del food and beverage evolve verso forme di **visibilità end-to-end, intelligenza decisionale, digital twin, IA agentica**. **Lo evidenzio, perché in Italia già l'80% degli operatori della GDO investe in digitalizzazione**, ma solo il **26% in multicanalità** con un evidente divario tra digitalizzazione interna e integrazione omnicanal. Per esempio, solo nella logistica del freddo: il tasso di crescita composto per garantire qualità dei prodotti sensibili previsto nel periodo (2025-2030) è **stimato nel 16,7%**. Anche il crescente **uso di centri di comando** e di **reti collaborative multi-impresa** che assicurano una maggiore resilienza e reattività dei loro sistemi di vendita, è un fattore che sta determinando novità rilevanti. Ad esempio, si pensi al caso di **Authentico** col proprio Passaporto Digitale di Prodotto (DPP) disponibile in 88 lingue che facilita oltre modo sia l'export che la sua compliance. Potremmo citarne altri di casi di successo italiani: dal Pastificio Di Martino, all'azienda pasticceria **Olivieri 1882**, da **Rosso Fine Food**, la **piattaforma B2B** rivolta ai professionisti del *food and beverage* che ricercano prodotti alimentari italiani di alta qualità), al pastificio **Agricolo Mancini**, che adotta sistemi di blockchain e QR code, per una tracciabilità automatizzata in tutte le fasi produttive (raccolta grano, molitura, trafilatura, confezionamento); si pensi anche all'azienda **Princes Industrie Alimentari** che trasforma il pomodoro attraverso tecnologie blockchain e QR Code, dati immutabili assicurando con certezza sia l'origine che la sostenibilità del prodotto.

E' certamente necessaria una strategia di azione per stabilire percorsi inclusivi per la scalabilità di soluzioni tecnologiche. Quali sono **le aree prioritarie e le condizioni per la scalabilità**? Ne segnalo cinque che rimetto al confronto:

1. **Investimenti infrastrutturali e tecnologie più robuste**, con l'obiettivo di: ridurre i costi e aumentare l'efficienza. Azioni concrete: diffusione di sensori IoT a basso costo e dispositivi connessi per monitoraggio continuo (temperatura, umidità, shock). L'adozione di forme di blockchain ibrida (pubblico- privata) per ridurre costi di notarizzazione e garantire interoperabilità. La disponibilità di piattaforme cloud scalabili per gestire grandi volumi di dati di filiera. Questo presuppone una

collaborazione tra risorse pubbliche e private (PNRR, Horizon Europe, Digital Europe), il coinvolgimento di provider tecnologici, PMI, autorità regolatorie. Sulla falsariga di quanto è stato già realizzato in UE con la piattaforma multi-stakeholder per la sicurezza FoodSafety4EU (Horizon Europe) con progetti gemmati in piattaforme blockchain + IoT, o quanto fatto negli USA: FDA “*New Era of Smarter Food Safety*” che ha previsto importanti incentivi per favorire la diffusione di tecnologie RFID e IoT.

2. **Standard globali e governance dati**, con l’obiettivo di: evitare l’eccessiva frammentazione normativa e i costi di compliance. Azioni concrete: l’implementazione di EPCIS (Electronic Product Code Information Services) lo standard GS1 per la codifica e lo scambio in tempo reale di dati sulla tracciabilità. Favorire la creazione di protocolli aperti per interoperabilità cross-border. L’istituzione di organismi terzi neutrali (es. GS1, Codex Alimentarius) per promuovere l’armonizzazione dei sistemi. Sulla falsariga di quanto già realizzato con le anagrafiche di prodotto condivise tra distributore e produttore: GS1 Global Standards, già adottati da Walmart, Carrefour. Le piattaforme blockchain per la tracciabilità alimentare (IBM Food Trust, TE-FOOD) con protocolli comuni per dati di filiera, protocolli aperti, organismi terzi per armonizzazione.
3. **Formazione e consulenza per le PMI**, con l’obiettivo di: supportare i produttori su piccola scala nella compliance, attraverso azioni concrete: la somministrazione di programmi di formazione su tracciabilità, normative (FDA Food Safety Modernization Act negli USA, o il Passaporto Digitale di Prodotto DPP nell’UE). Oppure l’erogazione di servizi di consulenza per implementazione e audit, e di voucher e incentivi per la digitalizzazione (es. Digital Skills & Jobs EU). Esempi operativi: il FAO & l’International Trade Center: il toolkit per l’export compliance. Carrefour Academy: corsi su blockchain e IoT per fornitori.
4. **Ecosistemi collaborativi**, con l’obiettivo di: creare hub digitali per la condivisione di dati e indicatori KPI per misurare gli obiettivi e impatti ESG, attraverso azioni concrete: la condivisione di piattaforme multi-impresa per tracciabilità e reporting sostenibilità, l’integrazione con sistemi di certificazione (ISO, GFSI **Global Food Safety Initiative**). Esempi operativi: IBM Food Trust → network globale per tracciabilità alimentare.
5. **Integrazione con e-commerce e omnicanalità** con l’obiettivo di: portare la tracciabilità fino al consumatore finale, attraverso azioni concrete: QR Code dinamici per lo storytelling del prodotto che consentono di collegare il packaging fisico a esperienze digitali in continua evoluzione, come video, recensioni, tutorial, e realtà aumentata, senza dover ristampare i codici, le funzioni di engagement (la gamification, i programmi fedeltà) basate su dati di tracciabilità che utilizzano i dati comportamentali degli utenti per creare esperienze personalizzate e stimolare l’interazione con i potenziali consumatori. Il digitale oggi non si limita a creare opportunità di acquisto a distanza, ma influisce anche sugli acquisti tradizionali: prima di un acquisto in negozio, **in quattro casi su dieci i consumatori consultano almeno un servizio online per acquisire informazioni**. Questo aspetto riguarda principalmente prodotti e servizi che impegnano l’acquirente in un processo di selezione e di valutazione delle alternative. Sebbene le abitudini dei consumatori siano sempre più improntate all’omnicanalità e diverse insegne retail italiane offrano la possibilità di acquistare online i propri prodotti già disponibili nei punti di vendita fisici, **un’insegna su dieci non si è ancora attivata nell’e-Commerce** e serve il proprio cliente solo attraverso il canale tradizionale. Come ha rilevato il Consorzio Trend Netcomm: solo il 26% delle aziende ha una omnicanalità avanzata, dunque si prospetta in questo campo una notevole opportunità di scalabilità.

Su ognuno di questi spunti, c’è un track record, ci sono progetti in attuazione, casi di successo da scalare, partnership strategiche già in essere.

*Il paper è tratto dallo studio realizzato nel 2025 dal Dr. Francesco D’Ausilio dal titolo “**Digital technologies and food traceability in europe through the analysis of the strategic dialogue on the future of the EU Agriculture**” che si allega.

English Version

Food security and the role of innovation in accelerating the transformation of food systems. *

Dr. Francesco D'Ausilio

Farmers, livestock breeders, processors, packagers, transporters, distributors, retailers and consumers ensure the functioning of the food system. Every day, supply chains produce, process and distribute a wide range of food products to billions of consumers around the world and provide sustenance to hundreds of millions of people with fresh agricultural products and processed foods. Food shortages, pre- and post-harvest losses, unsustainable use of land, water and energy, food waste, food fraud, unethical commercial practices, fair labour and climate change are all challenges that supply chains face on a daily basis.

Digital innovation is crucial in the management of food supply chains. Sustainability, quality and safety are enormous and complex issues. Every choice in this regard involves a financial and organisational cost. Compliance with standards, knowledge among stakeholders and interconnection in the multi-level food supply chain. Compliance of procedures and systems with frequently changing regulations. These are the headlines of an undertaking that requires systemic change.

We are at a crucial juncture in the debate on the future of European agriculture and agri-industry. The transformation that European agriculture is undergoing focuses on the transition to a more sustainable and equitable model, addressing challenges such as climate change, rising production costs and the need for modernisation. Climate, agricultural productivity, business competitiveness, farmers' incomes and agricultural product prices are just some of the issues at stake. The choices made, for example on trade rules and income support instruments starting with the post-2027 CAP, will be the litmus test. The transition is complex and fraught with tension. The highly polarised debate on the impact of the ecological and digital transition in agriculture in recent years is proof of this. The Strategic Dialogue on the future of EU agriculture, promoted in 2024 by the Commission, marked a positive development, at least in terms of methodology, for renewed collaboration between farmers, businesses, industry and civil society. We will measure its effects in the coming years.

This is where digital innovation comes into play. In 2017, the World Economic Forum published a report (*Innovation with a Purpose: The Role of Technology Innovation in Accelerating Food Systems Transformation*) that identified twelve technologies with the potential to improve food systems. Traceability was one of them. We are aware that it is not a miracle solution, but it does offer distinctive promise in helping to drive the transformation of food systems. It has the potential to strengthen inclusiveness and empower small-scale producers, ensuring them greater visibility in the market and access to new services and resources. In other words, the ability to transform complex data into concrete decisions: irrigating when needed, predicting climate stress, reducing waste, improving resilience and providing information throughout the supply chain. Technological tools are the enablers of the ecological and digital transition in agriculture and agri-food. Enablers that transform uncertainty into operational information, improving the ability of agroecosystems to anticipate, absorb and adapt to shocks, and contributing to the construction of a food system that is certainly more stable and resilient.

The digital transition in agriculture is certainly not a walk in the park. We are referring to a market, that of agriculture 4.0, which has a significant value in Italy (2.3 billion euros). The trends in the scale of digitalisation in Italy, tracked by the Smart AgriFood Observatory of the Politecnico di Milano, confirm this. I will mention a few: the slowdown in the agriculture 4.0 market in 2024 due to the reduction in public incentives, the decline in agricultural incomes and the investments already made in previous years; the technological maturity rate of companies, which is still relatively too low; and, finally, the propensity to invest and adopt technologies, which is still too closely linked to the size of the company.

The analysis of the data reveals some encouraging signs. I am thinking of the increase in demand for digital solutions from businesses, with an increase in investment in management software for farms (FMIS-Facilities

Management Information System for 13.5% of the total), Decision Support Systems (DSS, for 9.5%) and tools for monitoring and mapping crops and soils (9% each); I am thinking of the general growth in awareness among farmers of the digital paradigm, driven by an interest in improving their forecasting capabilities, as well as the control and management of their farms. Field protection ranks only third. Finally, I am thinking of the increase in the area cultivated with digital technologies in Italy, which has grown, albeit slightly, from 9% in 2023 to 9.5% in 2024.

But that's not all. The attention paid to the evolution of artificial intelligence in the sector is significant, with a 22% increase in the number of start-ups offering solutions based on AI and machine learning. In fact, about one-third of new agriculture 4.0 solutions in Italy are based on these technologies, applied to the management of field activities, crop protection and the optimisation of the use of resources such as water and agrochemicals. But carbon farming (I am referring in particular to practices to reduce emissions and increase carbon storage in soil and vegetation, with business models that reward those who adopt these practices) is also marking the growth of a market, albeit a predominantly voluntary one, focused on specific crops and livestock farming, where two-thirds of funded projects use digital tools. Finally, artificial intelligence is also playing a key role in food processing, artificial intelligence is playing a key role, especially in monitoring the sustainability and quality of products, with a particular focus on protecting quality certifications such as PDO and PGI, which, as highlighted in the ISMEA 2025 Report, will reach a turnover of over €20 billion in 2024, contributing 19% to the total turnover of the national agri-food sector.

The expected benefits of digitisation on food safety are significant. Operational efficiency: reduced waste, faster time-to-market. Traceability and compliance: rapid response to recalls, reduced legal risks. Brand trust and sustainability: transparency on origin and environmental impact. Positive return on investment (ROI): expected thanks to reduced operating costs and process optimisation.

The key trends in technology adoption in the supply chain are extremely interesting and are characterised by the adoption of blockchain technologies used for end-to-end traceability, transaction security and ESG compliance, IoT for real-time monitoring (temperature, location, environmental conditions) and RFID for low-cost traceability. In general, trends are characterised by the growing use of AI and digital twins to easily simulate and optimise complex systems, revolutionising Product Lifecycle Management (PLM) in the supply chain with new levels of integration, synchronisation and collaboration.

The obstacles and critical components that need to be addressed in order to accelerate the transition are not insignificant. The costs of adopting new technologies, the need for specific technical skills for their use and maintenance, and the risk of creating a digital divide between large and small companies, leaving the latter behind. But also the need for network infrastructure, especially in rural areas, and the lack of interoperability between different platforms and machinery, which makes system integration difficult. Data governance, through the sharing of sensitive information along the supply chain, requires common standards, interoperability between systems and solid security and privacy guarantees. The development of data infrastructure through stable access to satellite data, IoT networks and automatic weather stations. The availability of regional data hubs to share information and analytical tools between farmers, consortia and researchers. Only by removing these obstacles will traceability and interoperability be truly effective. Only if supported by shared protocols, clear rules on data ownership and access, and adequate security guarantees will they be able to realise their development potential.

The path to implementing technology-enabled end-to-end traceability systems in food value chains is neither straightforward nor short. The commercial implications of traceability benefits, starting with more effective access to international markets where traceability is a key requirement, for example, is an area that needs to be addressed. International markets where 54% of Italian companies struggle to expand due to digital and regulatory barriers, and where non-compliance is a serious obstacle to export opportunities. Among the additional benefits of traceability, we cannot fail to mention the removal of barriers to data flows, where privacy and localisation very often complicate the global operations of companies. I would also mention the adoption of new business models that include omnichannel retailing (integration between online and physical channels), marketplaces (platforms that connect buyers and sellers) and sustainable packaging (eco-friendly

packaging that minimises environmental impact). Experiences, channels and products that respond to growing consumer demand; and finally, I would mention the effect on brands and sales determined by product traceability: we know that 70% of consumers are more likely to buy traceable products.

The supply chain in the food and beverage sector is evolving towards forms of end-to-end visibility, decision-making intelligence, digital twins and agentic AI. I highlight this because in Italy, 80% of large-scale retailers are already investing in digitalisation, but only 26% are investing in multi-channel strategies, with a clear gap between internal digitalisation and omnichannel integration. For example, in cold chain logistics alone, the compound growth rate to ensure the quality of sensitive products over the period (2025-2030) is estimated at 16.7%. The growing use of command centres and multi-company collaborative networks, which ensure greater resilience and responsiveness of their sales systems, is also a factor that is bringing about significant changes. Take, for example, Authentico with its Digital Product Passport (DPP) available in 88 languages, which greatly facilitates both exports and compliance. We could mention other Italian success stories: from Pastificio Di Martino to the pastry company Olivieri 1882, from Rosso Fine Food, the B2B platform aimed at food and beverage professionals looking for high-quality Italian food products, to the pasta factory Agricolo Mancini, which adopts blockchain and QR code systems for automated traceability in all stages of production (grain harvesting, milling, extrusion, packaging); Consider also Princes Food Industries, which processes tomatoes using blockchain and QR code technologies, immutable data that guarantees both the origin and sustainability of the product.

A strategy for action is certainly needed to establish inclusive pathways for the scalability of technological solutions. What are the priority areas and conditions for scalability? I would like to highlight five that I would like to put forward for discussion:

1. Infrastructure investments and more robust technologies, with the aim of reducing costs and increasing efficiency. Concrete actions: dissemination of low-cost IoT sensors and connected devices for continuous monitoring (temperature, humidity, shock). The adoption of hybrid (public-private) blockchain forms to reduce notarisational costs and ensure interoperability. The availability of scalable cloud platforms to manage large volumes of supply chain data. This requires collaboration between public and private resources (PNRR, Horizon Europe, Digital Europe), the involvement of technology providers, SMEs and regulatory authorities. Along the lines of what has already been achieved in the EU with the multi-stakeholder platform for food safety FoodSafety4EU (Horizon Europe) with projects based on blockchain + IoT platforms, or what has been done in the US: FDA “New Era of Smarter Food Safety”, which has provided significant incentives to promote the spread of RFID and IoT technologies;
2. Global standards and data governance, with the aim of avoiding excessive regulatory fragmentation and compliance costs. Concrete actions: implementation of EPCIS (Electronic Product Code Information Services), the GS1 standard for real-time coding and exchange of traceability data. Encourage the creation of open protocols for cross-border interoperability. The establishment of neutral third-party bodies (e.g. GS1, Codex Alimentarius) to promote the harmonisation of systems. Along the lines of what has already been achieved with product registries shared between distributors and manufacturers: GS1 Global Standards, already adopted by Walmart and Carrefour. Blockchain platforms for food traceability (IBM Food Trust, TE-FOOD) with common protocols for supply chain data, open protocols, third-party bodies for harmonisation;
3. Training and consulting for SMEs, with the aim of: supporting small-scale producers in compliance through concrete actions: the provision of training programmes on traceability and regulations (FDA Food Safety Modernisation Act in the US, or the Digital Product Passport DPP in the EU). Or the provision of consulting services for implementation and auditing, and vouchers and incentives for digitisation (e.g. Digital Skills & Jobs EU). Operational examples: FAO & International Trade Centre: the export compliance toolkit. Carrefour Academy: courses on blockchain and IoT for suppliers;
4. Collaborative ecosystems, with the aim of: creating digital hubs for sharing data and KPIs to measure ESG objectives and impacts, through concrete actions: sharing multi-company platforms for traceability and

sustainability reporting, integration with certification systems (ISO, GFSI Global Food Safety Initiative). Operational examples: IBM Food Trust → global network for food traceability;

5. Integration with e-commerce and omnichannel retailing with the aim of: bringing traceability to the end consumer through concrete actions: Dynamic QR codes for product storytelling that connect physical packaging to constantly evolving digital experiences, such as videos, reviews, tutorials, and augmented reality, without having to reprint codes; engagement features (gamification, loyalty programmes) based on traceability data that use user behaviour data to create personalised experiences and stimulate interaction with potential consumers. Today, digital technology is not limited to creating remote purchasing opportunities, but also influences traditional purchases: before making a purchase in a shop, four out of ten consumers consult at least one online service to gather information. This mainly concerns products and services that require the buyer to engage in a process of selection and evaluation of alternatives. Although consumer habits are increasingly omnichannel-oriented and several Italian retailers offer the possibility to purchase their products online that are already available in physical stores, one in ten retailers has not yet entered the e-commerce market and serves its customers only through traditional channels. As noted by the Trend Netcomm Consortium: only 26% of companies have advanced omnichannel capabilities, so there is considerable opportunity for scalability in this area.

For each of these ideas, there is a track record, projects are being implemented, success stories to scale, and strategic partnerships already in place.

*The paper is taken from the study conducted in 2025 by Dr Francesco D'Ausilio entitled “Digital technologies and food traceability in Europe through the analysis of the strategic dialogue on the future of EU agriculture” attached hereto.

Paper

Digital Technologies and Food Traceability In Europe Through The Analysis of the Strategic Dialogue on the Future of the Eu Agriculture.

Dr. Francesco D'Ausilio

Abstract

The paper addresses the pivotal role of digital traceability in food safety, unveiling critical components in technology-driven solutions and gaps in the European agri-food sector in meeting farmers' and agri-business concerns and expectations. The investigation is conducted through a critical discourse analysis of the report of the *Strategic dialogue on the future of the EU agriculture* that, since January 2024, brought together major stakeholders from the European agri-food sectors, civil society, rural communities, and academia to reach a common understanding and vision for the future of the EU's farming and food systems. Through primary and secondary sources provided by EU regulations and official and unofficial reports, the analysis attempts to frame in a historical framework the concerns expressed by the stakeholders, and the market drivers for the enhancement of digital traceability. Ultimately, the paper contributes to the scholarly discourse on the limits and opportunities of digital technology in traceability, providing a set of recommendations for policymakers, agri-food stakeholders, and academia.

Keywords: food traceability systems; agri-food sector; supply chains; digital technologies; EU; strategic dialogue; sustainability

1. Introduction

Food traceability in the European Union is an important aspect of food safety and quality assurance that is governed by a complicated regulatory framework. This system ensures that food products can be tracked throughout the supply chain, increasing consumer trust and safety.

Regulation (EC) No. 178/2002 is the foundation of food traceability in Europe, establishing fundamental principles such as transparency, traceability, and producer responsibility, and representing a significant achievement in EU food legislation. This rule imposes several restrictions on food industry operators, such as product labeling, risk communication, and withdrawal procedures. According to studies, traceability has a major impact on consumer perceptions of food quality and safety, making it a competitive issue in the agri-food industry (Giraud and Halawany, 2006).

Food tracking was previously done using paper records, labels, and tags that were filled out and recorded by a human operator. Beyond that, food could not be tracked "live". If there was a problem with a food product, it was hard to figure out what caused it and when it happened. Furthermore, human error during the documentation process may result in potentially problematic circumstances. On the other hand, using the current methods to fulfill the requirements became more laborious in an era of globalisation and rising food demand, and there was a greater chance of unanticipated, serious issues.

According to King (2017), digital technologies have the potential to significantly transform agricultural systems. In the European agri-food industry, digital technologies are transforming food safety procedures and providing innovative solutions to pressing supply chain issues. To address the challenges of food traceability, it is essential to integrate tools like blockchain for traceability, Internet of Things (IoT) sensors, and big data for real-time monitoring, and artificial intelligence for predictive analytics. This allows customers to access comprehensive product histories and verify quality. According to Abbate et al. (2023), digital transformation is a complicated topic that is expressed in numerous branches of practice and analysis. Higgins et al. (2017) demonstrate how various ordering processes and strategies may contribute to the widespread adoption of

agricultural digitalisation, which can assist actors in dealing with digital constraints. There are significant discrepancies between the expectations of farmers and agribusinesses and the solutions that are currently available, although the advancements promise increased efficiency and transparency. High implementation costs, a lack of standardisation, and inadequate digital infrastructure in rural areas are issues that many stakeholders face.

While the experience of stakeholders is an important factor influencing farmers' adoption of digital technologies (Engas et al., 2023; Moretti et al., 2023), a major obstacle to digital innovation is the lack of access to data and digital infrastructure (Mehrabi et al., 2021). According to reports, the way farmers operate and their role in the supply chain are significantly impacted by the early implementation of digital technologies (Klerkx et al., 2019; Forney and Dwiartama, 2023; McGrath et al., 2023). To guarantee widespread adoption, more user-friendly interfaces and thorough training programmes are also required. To fill these gaps, technology businesses, policy-makers, and industry stakeholders need to collaborate to create specialised solutions that satisfy the unique requirements of the European agri-food sector while guaranteeing adherence to rigorous food safety regulations.

Beyond satisfying customer demands, digital traceability can be deployed to promptly address food safety issues, make it easier to identify the exact sources of contamination, and successfully reduce the risk of foodborne illness. As a result, national governments all over the world have started to develop and put into effect policies that incorporate digital traceability into their agri-food frameworks. The need for this kind of integration stems from the understanding that digital traceability is essential to guaranteeing the security and safety of food. Governments aim to create a culture of traceability and accountability across the whole food supply chain by passing the necessary regulations, setting standards and requirements, and providing incentives for adoption. A recent study highlights the benefits of robust digital traceability systems, showing a lower incidence of foodborne illness and increased consumer trust in food product safety and quality (Demestichas et al., 2020). As a result, governments aiming to protect public health, promote sustainable agriculture, and support economic growth in the agri-food industry must strategically develop and implement policies to strengthen digital traceability.

The paper addresses the pivotal role of technology in the process of food traceability in Europe to:

- consider the spread of technologies and digital systems for tracking and tracing food products;
- analyse the impacts and the concerns expressed by the agri-food stakeholders, consumers included;
- examine the constraints on access to technologies and the interoperability issues between systems that affect their scalability and investment costs;
- explore the market drivers for the enhancement of digital traceability;
- contemplate the limits to regulatory compliance, given that the different national regulations can complicate the implementation of uniform traceability systems across the continent.

The paper explores the European debate on digital traceability systems, providing a historical framework that has gained significant attention in recent years due to concerns about safety, quality, and transparency in the food supply chain. Key aspects of this debate include:

1. **Regulatory framework:** Meeting EU regulations on food safety and labeling, such as Regulation (EC) No 178/2002.
2. **Technology adoption:** Discussing the use of advanced technologies like blockchain, RFID, and IoT for improving traceability systems and their potential benefits and challenges.
3. **Consumer trust and transparency:** Addressing consumer demands for more information about food origins, production methods, and ingredients to build confidence in the food supply.

4. **Supply chain complexity:** Challenging the implementation of traceability systems across complex, global supply chains and ensuring cooperation among all stakeholders.
5. **Cost implications:** Debating the economic impact of implementing comprehensive traceability systems on food producers, processors, and retailers.
6. **Data management:** Exploring the concerns about data privacy, security, and standardization in traceability systems.
7. **Sustainability:** Examining how traceability can support sustainable food production and consumption practices.
8. **Fraud prevention:** Using traceability as a tool to combat food fraud and mislabeling.
9. **Trade implications:** Discussing how traceability requirements may affect international trade and market access.
10. **Harmonization efforts:** Considering initiatives to align traceability standards and practices across EU member states and with international standards.

The ongoing debate among stakeholders aims to balance the need for robust traceability systems with practical implementation challenges and financial concerns.

The history of food traceability in Europe is extensive and dynamic, with notable advancements taking place in the late 20th and early 21st centuries. The concept became widely recognised in the 1990s after several food safety accidents, most notably the UK's bovine spongiform encephalopathy (BSE) outbreak. The necessity of thorough tracking systems across the food supply chain was brought to light by these incidents. Regulation (EC) No 178/2002, which created the European Food Safety Authority and established general guidelines for food traceability, was one of the regulations the European Union introduced in response. All food businesses were required by this regulation to be able to identify the suppliers of their items and the recipients of their products. Traceability requirements for particular food sectors, such as fish, beef, and genetically modified organisms, were further refined by later regulations. Throughout Europe, the deployment of these systems has greatly increased consumer confidence, food safety, and the capacity to handle food-related emergencies.

Besides the analysis based on its relationship with other supply-chain management concepts, including risk management (Ringsberg 2014) and sustainability (Garcia-Torres et al. 2019), there are noteworthy literature reviews on specific themes of traceability, such as technology (Costa et al. 2013; Pournader et al. 2020; Wang, Han, and Beynon-Davies, 2019) and regulation (Borit and Santos, 2015). The advantages of traceability and its effect on supply-chain performance have also been examined, but these reviews have been restricted to either a specific technology, such as blockchain (Pournader et al. 2020; Feng et al. 2020) or RFID (Nambiar 2010; Costa et al. 2013), or to a specific industry, or food item (Opara 2003; Dabbene, Gay, and Tortia 2014), or computers and software (Omar and Dahr 2017; Mustafa and Labiche 2017). Thus, there is a need for a comprehensive review of the extent literature to integrate the benefits of traceability discussed across multiple industries and technologies.

The paper provides a critical discourse analysis of the report of the *Strategic Dialogue on the Future of EU Agriculture* that, in January 2024, brought together major stakeholders from the European agri-food sectors, civil society, rural communities, and academia to reach a common understanding and vision for the future of EU's farming and food systems. Announced by the President of the European Commission Ursula von der Leyen in her *State of the Union Address* on September 13th, 2023, and launched in January 2024, the *Strategic Dialogue on the Future of EU Agriculture* brought together twenty-nine major stakeholders from the European agri-food sectors, civil society, rural communities, and academia to reach a common understanding on the further development of a core area of European life and economy in a new format of political discourse. Mandated ad personam by the President of the European Commission, its members, coordinated by Peter

Strohschneider, Special Adviser to the President Chair of the *Strategic Dialogue on the Future of EU Agriculture*, had the task of working on four key issues relating to the prospects of farmers and rural areas, the preservation of planetary boundaries, the opportunities of technology and innovation and the future of the European food system.

The *Strategic Dialogue* dedicated itself to this challenging task in seven plenary sessions in Brussels as well as in an uncountable number of mainly virtual consultations and meetings of working groups or task forces. The moderators of the working groups played a role in the cohesion of the group of members and the development of shared perspectives. During its working phase, the *Strategic Dialogue* also undertook a targeted consultation of relevant European agri-food and environmental organisations. A scientific symposium and a technical workshop in April and July 2024 served to promote intensive exchange with agricultural scientists.

The participants of the *Strategic Dialogue* strove for a conceptual consensus that opened new perspectives for farming, food, and rural areas on the continent. Its final report serves as an orientation for action to create socially responsible, economically profitable, and environmentally sustainable agri-food systems. The report is addressed to the European institutions, in particular to the European Commission in all its related portfolios, and to the Member States. Through the process of the *Strategic Dialogue*, its members laid the ground for a new culture of engagement and cooperation that reflected their determination to work together for a sustainable, resilient, and competitive future.

The Dialogue comes in a time of considerable societal transformations in which the agri-food systems themselves are involved and which are significantly influencing them. Food and agriculture play an existential role and are at the very heart of European societies. However, while the central functions of farming and food will continue to be foundational, they are undergoing rapid change. This is driven most urgently by the triple planetary crisis of climate change, biodiversity loss, and pollution that is putting significant pressure on them. In addition, increasing global political and economic tensions have exacerbated challenges facing European societies, which also affect many farmers and agri-food actors. This is happening in a climate of increasing societal conflicts that intertwine with a growing urban-rural divide (Strategic Dialogue, 2024). Decisive actions are therefore required to address these fundamental challenges.

In the polarised agri-food policy debate on the ecological transition, the *Strategic Dialogue* marks a pivotal step towards fostering collaboration among farmers, industry, and civil society, though its effectiveness remains to be seen. The EU policymakers need to focus on driving the transformation of the food and farming system toward environmental, social, and economic sustainability, as initiated in 2019 with the *European Green Deal*. A key component of this is a revision of the *Common Agricultural Policy* (CAP) to encourage farmers to embrace sustainable practices, increase investment in sustainability, and lessen administrative burdens through digitisation, all while getting ready for the EU's next enlargement (Caiati & Pratelli, 2024).

The decision to examine the *Strategic Dialogue* has several significant and innovative benefits.

Firstly, it provides an analytical contribution that does not dwell expressively on the history and regulations of food traceability but rather on the perspectives of businesses, farmers' associations, unions, and consumers, then it provides a privileged vantage point on the functioning and impact of traceability systems. That is, starting from those subjects who have direct and indirect responsibility for the complex rules and procedures that govern the functioning of the entire food supply chain.

Secondly, it allows the paper to frame the biases and claims in a systemic approach, revealing the concerns and how they reflect different discourses on digital technology and food traceability. Focusing on the drivers/motivations, and the challenges/barriers that may inhibit its implementation. This is necessary given that there is a clear bond between these issues and the benefits achieved. For example, the choice and subsequent success of a traceability system is affected by: the reasons for its adoption, the functionality of available technologies, and how the supply-chain partners overcome any barriers to adoption. Thus, understanding these issues enables a deeper understanding of the benefits. A comprehensive understanding of

the benefits, in turn, enables the development of an understanding of the relationship between these benefits and the supplychains.

Both the first and the second benefits of the analysis provide an innovative contribution to the research and comprehension of the recent history of the European debate on food traceability.

As highlighted, the European debate on food traceability has historically evolved. This evolution was driven by European Regulation 178/2002, which established the general principles of EU food legislation and introduced the obligation of traceability throughout the entire production chain. Crossing various phases. In the early 2000s, the focus was on specific products. Before 2005, traceability was mainly required for high-risk products such as meat, fish, and eggs. In 2005, Regulation 178/2002, in force since January 1, 2005, made traceability mandatory for all food and feed, involving every stage of the chain, from production to distribution. The regulatory framework was implemented with the requirement for companies to implement traceability systems, documenting every incoming and outgoing flow, and ensuring the ability to trace every product along the supply chain. Then, further regulations, such as EU Regulation No. 625/2017, which replaced Regulations 854/2004 and 882/2004, and EU Regulation 382/2021, which updated Regulation EC 852/2004, have strengthened food safety regulations, including the aspect of traceability.

Over the past twenty years, alongside the evolution of the regulations, on one hand, the digitation and penetration of technology in traceability systems, and on the other hand, the impact of such innovations on regulatory and control authorities, businesses, consumers, and sector stakeholders, have led to a change in the orientations and choices of the European Commission. On the analysis of this alleged change, the research will focus its attention.

The EU's recent initiatives to encourage the adoption of digital technologies in the agri-food industry have been successful. The European Commission has supported various research and innovation projects (such as ATLAS, DEMETER, projects both funded by the European Union under the Horizon 2020 program) and dissemination actions, such as the *European Common Agricultural Data Space*, which shapes the digitalisation of EU agriculture (<https://digital-strategy.ec.europa.eu/it/policies/digitalisation-agriculture>). I will thoroughly analyse these measures in the following sections.

The sector is facing emerging issues. The increase in the use of digital applications in agriculture has led to a greater amount of data, which is highly specific and diversified. The collection of agricultural data includes land, crops, livestock, agronomic data, climatic data, machine data, financial data, and compliance data. Some data might be considered personal or sensitive by farmers, such as data on tractor routes or factors leading to successful production. Other data might be considered confidential by agribusinesses. Agricultural data, especially if available for many farms, is economically important not only for farmers but also for the entire value chain, for example, for market forecasts, product development, and insurance. Farmers fear that their data may be used by third parties without their consent or knowledge. Protecting trade secrets is nowadays essential. It is therefore essential to ensure guarantees for data sharing, data sovereignty, and data security to build trust and not compromise the further development and acceptance of smart agriculture. To facilitate fair data sharing between sectors, the EU has adopted the data regulation, which is coming into effect in 2025. The *EU Code of Conduct on Agricultural Data Sharing*, established by a group of associations from the EU agri-food supply chain, provides guidelines on the use of agricultural data, particularly regarding access and usage rights (EU Code of Conduct on Agricultural Data Sharing by Contractual Agreement, 2024). In the *European Data Strategy* (2020), the EU Commission announced the *Common European Agricultural Data Space* (CEADS) to facilitate the reliable sharing of agricultural data between private stakeholders (such as farmers, machinery manufacturers, and data service providers) and public authorities. With funding from the *Digital Europe initiative*, the implementation takes a step-by-step approach, beginning with the preparatory activity "*AgriDataSpace*" (2024) and concluding with a diffusion action. Designing a European framework for a secure and trusted data space for agriculture may be part of a broader historicisation process, in terms of the evolution of the discourse and the existing landscape of the initiatives shared by the agri-food stakeholders.

The paper adopts a systematic literature review approach to address the gaps recalled and the research questions previously mentioned.

The paper is structured as follows. Section 1 introduces the scope of the research and the research questions. Section 2 provides a literature review, which includes the background information required to answer the research question in terms of traceability drivers, the evolution of technology, and the barriers to implementation. Section 3 outlines the methodology adopted in the paper. Section 4 then discusses the findings concerning the analysis of the Strategic Dialogue and other EU programmes, reports, and statistics. Section 5 provides the results achieved and provides a discussion on the findings of the paper. Section 6 draws a conclusion, identifies the research gaps, and suggests potential future research directions.

2. Literature Review

The broader context: why is this area worth exploring?

The literature review intends to demonstrate how the paper fits within the broader context of existing contributions to the ongoing debate on food safety, specifically food traceability.

Some high-profile public health alarms in the 1980s and 1990s caused a focus on integrating efficient food safety management systems into food businesses and guaranteeing improved regulatory control of intricate food supply chains. Despite the investment in both regulatory and private governance systems, food safety emergencies continue to occur. These problems have highlighted the importance of material and product traceability. Effective food traceability systems are becoming more and more important for stakeholders, particularly those who seek to operate sustainably and communicate this to their customers. Product analysis and failure detection are one element within the complex validation, monitoring, and verification programmes that are adopted to assure food safety and consistent compliance with quality criteria defined within product specifications, and that any product claims (e.g., natural, sustainable, organic) can be justified. To reduce the possibility of product incidents in the first place, preventative, systems-based approaches must be used in conjunction with final product testing, which is never an adequate method for monitoring food safety, quality, and integrity on its own (Henson & Caswell, 1999; Zwietering et al., 2016).

This issue has been evidenced by the fact that the *Hazard Analysis and Critical Control Point* (HACCP) system has become mandatory along the food supply chain, post-harvest and post-slaughter in the European Union (EU) and the USA. This has been the case since the 1990s when HACCP principles were adopted by the *Codex Alimentarius Commission* (CAC). In 2020, CAC adopted the revised *Code of Practice* (General Principles of Food Hygiene (CXC 1-1969) which entailed additional guidance on allergen management, management commitment to food safety, including the maintenance of a positive food safety culture, and promoting continual improvement as science and technology evolve (FAO, 2023). The outbreak of the COVID-19 pandemic and the implementation of pandemic-related restrictions affected the operation of food safety procedures along the supply chain and, consequently, exposed the need to reinforce good hygiene practices and systematically improve the traceability/product tracing system, especially to enable quick and effective recall of non-compliant products. The convergence of conflicts, COVID-19, and climate crises makes the role of technology in ensuring effective traceability and transparency essential. (Kowalska et al. 2023)

Industry 4.0 technologies, including Blockchain technology, cloud computing, Internet of Things (IoT), etc., have a specific role in making the agri-food supply chain ‘smart enough’ to address contemporary issues (Yadav et al. 2022). The use of these technologies could make the agri-food supply chain more data-driven, intelligent, and agile, crucial both in routine supply operations and in the event of an emergency, such as a product recall or a pandemic (Kowalska et al. 2023).

Ensuring the safety, integrity, and traceability of our food supply becomes a challenge in the complex and constantly changing world of global food production and distribution. In addition to bringing about revolutionary solutions that have an impact on all facets of the food supply chain, the emergence of digital technologies has signaled a new era in how we approach these problems (Ali Eltabey, 2023).

The key factor reshaping the food supply chain is the Internet of Things (IoT), which is frequently hailed as a revolutionary force. The Internet of Things (IoT) enables not only the collection but also the continuous, real-time flow of data across various stages of food production, transportation, and storage through an intricately woven network of interconnected devices embedded with a variety of sensors. A rapid, focused, and data-driven response to possible threats is made possible by this interconnectedness, which goes beyond the traditional limits of monitoring and ushers in an era of proactive surveillance and early detection systems. The applications of IoT in the food industry are wide-ranging and revolutionary, and redefine the concepts of operational efficiency, from smart logistics improving supply chain efficiency to precision agriculture optimising resource usage (Ali Eltabey, 2023).

Celebrated for its immutable ledgers, transparency, and security features, blockchain technology is leading the charge to transform food supply chain traceability. Blockchain ensures an unprecedented level of transparency by permanently recording every minute detail of the journey food products take, from their origin at the farm to their final destination at the consumer's table. This reduces the impact of foodborne outbreaks by accelerating the identification of contamination sources and coordinating a meticulously planned recall procedure. A layer of trust and accountability is added by the decentralised and impenetrable nature of blockchain, which successfully rewrites the story of transparency and reliability throughout the food supply chain (Ali Eltabey, 2023).

A key component of the digital transformation of food safety is data analytics, which leverages the power of artificial intelligence and sophisticated analytics techniques. Beyond the traditional domains of historical data analysis, real-time convergence of predictive modeling, anomaly detection, and pattern recognition allows for the unparalleled interpretation of large datasets. This enhances overall risk management strategies by enabling the early identification of possible safety issues and bringing in a new era of proactive intervention measures. These procedures are further improved by the incorporation of machine learning algorithms, which create a framework that is flexible and dynamic in response to new threats and difficulties (Ali Eltabey, 2023).

Main challenges: What are the key research challenges in this research field?

The key research challenges in this paper are three.

Firstly, food traceability systems (FTS) need a certain extent of willingness among the actors across the supply chain to cooperate and share data and information. This intention constitutes a precondition for the functioning of the system, regardless of the technologies adopted. For this reason, it cannot be taken for granted.

FTS require interoperability both within individual organisations and across supply chains to go beyond tracking individual traceable resource units to developing a full transactional history for the lifecycle of the product (Newsome et al. 2013). This means designing and implementing traceability systems that contribute to the efficient collection, storage, processing, analysis, and use of data (Olsen & Borit, 2018). Mehrabi et al. (2021) successfully described a representation of bias that influences the process.

Among the benefits, Mehrabi et al. (2021) recall: brand protection, collation of data, compliance with legislation and certification requirements, effective functioning of supply chains, effective operational management, logistics, and distribution management, faster more accurate collection, retention, and reuse of data, inventory management and resource efficiency, reduced data loss, data security. Whilst, among the barriers, Mehrabi et al. (2021) recall: Inefficient data and knowledge management, information loss and lack of interoperability, lack of governance and agreement on common standards, lack of clear implementation strategies and pathways, and technology scaling issues, lack of resources, funding, and capacity to develop systems awareness, lack of skills and knowledge about traceability and traceability technologies

Beyond traceability, the chain of custody includes the responsibilities and controls at every stage of the supply chain concerning all inputs and outputs, information exchanged, and the potential effects on food sustainability, quality, and safety (Chopra, 2020). Indeed, in carbon certification programs and the tracking of verified sustainability benefits linked to food ingredients and packaging materials through supply chains, chain of

custody certification is becoming more and more significant (Vidal et al. 2005; Santoso et al. 2019); aquaculture and worker welfare (Funge-Smith et al. 2007; Seo et al. 2015; Sparks et al. 2022); and with agri-food certification standards such as LEAFMarque, which promote climate-positive farming and biodiversity (Pérez Perales et al. 2019).

According to Directive (EU) 2022/2464 regarding corporate sustainability reporting, food traceability systems may also make sustainability reporting easier, which will be required for some food business operators starting in 2024. It is reasonable to assume that the implementation of food traceability systems based on Blockchain technology will facilitate the collection of adequate data from stakeholders across their value chain, particularly from small and medium-sized suppliers as well as those in emerging markets and economies. According to Article 29b Sustainability reporting standards, and the preamble to Directive (EU) 2022/2464, gathering such data has been identified as one of the challenges that undertakings may face in sustainable reporting. (Kowalska et al. 2024).

A crucial component of food supply chain management, traceability shows how goods, materials, packaging, and processing aids have traveled through a business and across supply chains (Keogh et al., 2023; Sufiyan et al., 2019). Indeed, tracking and tracing of these items is both a legal and market requirement (Islam et al. 2021a). Regulation 91 (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority, and laying down procedures in matters of food safety defines traceability as the ability to trace and follow a food, feed, food-producing animal or substance intended to be, or expected to be incorporated into a food or feed, through all stages of production, processing, and distribution. Traceability involves the transactional processes of tracing materials and ingredients forward to the final product and, alternatively, tracking food products back to initial ingredients via all production steps. Demonstrating traceability underpins a range of aspects such as consumer confidence, openness, and transparency that in turn create trust relationships across food supply chains, and ultimately to the consumer (Manning et al. 2022).

Regulation (EC) No 178/2002 introduces, in section 2, the principles of transparency. These principles are: (1) public consultation (there shall be open and transparent public consultation, directly or through representative bodies, during the preparation, evaluation, and revision of food law, except where the urgency of the matter does not allow it); and (2) public information (public authorities shall take the appropriate steps to inform the general public where there are reasonable grounds to suspect that food may present a health risk). Whilst transparency in this context focuses on public consultation and public information from a regulatory stance in the industry, transparency can have additional perceived attributes. It will go well beyond the transactional aspect of batch traceability to reveal details about the activities that have taken place at every stage of production, in addition to the inherent characteristics of the product. The ability to map the entire supply chain and the activities that take place at each stage is the main goal of transparency. As a result, supply chain transparency precedes traceability. According to Kowalska et al. (2024), traceability information is just one component of the information that might need to be made publicly available to stakeholders and consumers, particularly in the event of a food recall.

Food traceability systems, their design, implementation, and evolution are influenced by a combination of different drivers, including regulations and the need to capture information on food safety, quality, and integrity, worker welfare, animal welfare, environmental protection, and sustainability requirements (Islam & Cullen, 2021). Islam et al. (2022) differentiate between internal food traceability systems that operate within an organisation and external ones that operate outside of the organisation. These internal food technology systems need to link together (interoperability), they argue, to create a chain of custody for a product. The benefits and barriers associated with food technology systems have been collated in Table 1 below. Barriers to the adoption of FTSS include: a lack of resources, funding, and capacity to develop systems awareness; a lack of governance and agreement on common standards; a lack of skills and knowledge about traceability and traceability technologies; inefficient data and knowledge management; a lack of clear implementation strategies and pathways and technology scaling issues (Badia-Melis 128 et al. 2015; Islam & Cullen, 2021)

Secondly, once the intention to collaborate has been verified, based on a regulatory choice, it is necessary to have smart and sustainable tracking systems in place. Smart systems can digitally connect supply chain actors from product development through the production planning process to the consistent production of food products that are safe and comply with product specifications (Schmidt et al. 2022). These product specifications will include food safety, quality, and sustainability requirements. Rabobank (2015) describes smart food systems as being “*more productive, more (globally) integrated, less wasteful and more profitable, more efficient in using resources to produce and deliver the food consumers’ need, where and when they need and want it, making it [the system] more sustainable.*” Adoption of ICTs has delivered business benefits across a range of business sectors through fast and accurate communication that supports “*improved decision making product development, quality of product, and service often measured through increased customer satisfaction*” (Schmidt et al. 2022, p. 276). As previously mentioned, several smart technology solutions facilitate smart food traceability, e.g., Blockchain technology, cloud computing, smart contracts, IoT, Artificial Intelligence (AI) (particularly machine learning), portable detection devices, smart indicators, and sensors integrated into food packaging (Yu et al., 2022). The technologies offer opportunities for developing smarter, more agile FTS. Kowalska et al. 2024 have summarized the advantages of the traceability of each technology:

Table 1: Advantages of technology used for traceability

Technology	Advantage
Barcodes and Tags, e.g., 1D, 2D barcodes, QR codes, RFID tags	Technology that can travel with the batch and store the history of the batch through the supply chain
Blockchain	Immutable, tamperproof records of transactions across a supply chain
Cloud computing	Remotely stored data that is accessible and shareable on demand
Digital information platforms	Permissioned access to traceability data
Digital twins	Modeling and mimicking the physical environment supporting information flow and traceability practices
IoT (including RFID, barcodes, sensors, and software)	Real-time collation of data for a particular batch(s)
Machine learning, algorithms, and artificial intelligence	Combining technologies can support traceability systems and decision tools.
Smart-phone applications	Opportunity for in-situ monitoring and verification activities to support food safety assessments and traceability systems

Source: Kowalska et al. 2024

Existing systems of communication have a crucial role in ensuring greater traceability and transparency of information sharing between manufacturers, distributors, consumers, food control institutions, and other stakeholders. These include the *Rapid Alert System for Food and Feed* (RASFF), the *TRAdE Control and Expert System* (TRACES), and the *European Union Notification System for Plant Health Interceptions* (EUROPHYT). These systems have been integrated into the *Information Management System for Official Controls* (IMSOC) to make information exchange timely and efficient.

Both the EUROPHYT and TRACES databases run by the Directorate General for Health and Food Safety (DG SANTE) of the European Commission facilitate the exchange of data and documents between trading parties and control authorities, hence contributing to increased transparency. TRACES has been compulsory since 2015, but the electronic certification capability of TRACES NT (New Technology) has revolutionised traditional sanitary and phytosanitary certification practices. It has enabled both EU and non-EU authorities to stamp digitally official documents and certificates required for the importation of animals, animal products, food, feed, and plants into the EU, and the intra-EU trade and EU exports of animals and certain animal

products (ESCAP, 2023). The electronic transmission of documents makes international food trade more transparent and sustainable regarding saving paper and energy, lowering emissions, etc. Digitisation means reduced administrative burden for food business operators. It may contribute to the development of entrepreneurship and promote fair practices along food supply chains.

Thirdly, transparency in a supply chain is the extent to which all its stakeholders have a shared understanding of and access to the product-related information that they request without loss, noise, delay, and distortion (Hofstede et al. 2003; Deimel et al. 2008). Transparency in agri-food supply chains can be demonstrated via the application of organisational arrangements for information flow and exchange within organisations and between actors (Pant et al. 2015). Supply chain transparency is both an important and a difficult goal to achieve (Abeyratne & Monfared 2016; Astill et al., 2019). Furthermore, organisations are faced with the need to choose between retaining some information as confidential and thus not shared, e.g., the company secrets that are the source of their competitiveness, and, in other contexts, sharing data with others and its meaning, and acting with full transparency.

Enhancing supply chain visibility and establishing the chain of custody through efficient end-to-end supply chain information sharing are two ways to achieve supply chain transparency (Smart et al. 2008). Increased supply chain transparency is driven by several factors, including the necessity of a strong chain of custody to validate sustainability claims, efficient resource management and optimisation to minimise food loss and waste, effective risk and recall management, preventing outbreaks of foodborne illness, and meeting evolving consumer demands (Astill et al. 2019).

Therefore, transparency is linked to the extent to which supply chain participants can access information and data both individually and collectively. Although governance structures and trust frameworks can be used to define transparency (Brewer et al., 2021), normative standards like accountability, justice, responsibility, and rights also frame transparency (Mol, 2015). Jakku et al. (2019) contend that the adoption of smart farming systems may be constrained by a lack of trust and transparency, particularly concerning data ownership and who stands to gain from the integration of smart farming technologies.

State of the art: what has been done so far? Projects, research, studies.

The review connects different studies to identify common themes, debates, and emerging trends in food digital traceability.

A recent study has provided an analysis and comparative review of traceability regulations, strategies for information dissemination, collaborative efforts among stakeholders, and regulatory frameworks concerning agri-food products across OECD member states (Charlebois et al. 2024). The study provides a comprehensive overview of each nation’s efforts to integrate digital food traceability into their respective national agendas, offering actionable recommendations and insights to policymakers, businesses, and other key stakeholders in the agri-food supply chain to facilitate the efficacious deployment of digital traceability systems while addressing any challenges that emerge. The study conducted extensive investigations on all 38 member countries of the OECD. Additionally, the analysis extended to the European Union, particularly focusing on its twenty-three member states that are concurrently part of the OECD (Charlebois et al. 2024).

According to this study, the integration of digital traceability in the agri-food business is undergoing a substantial shift across the globe, with variable degrees of advancement and adoption. Countries are at varying levels of integrating digital traceability, and this disparity has created an intriguing landscape that provides significant insights into the future of the agri-food business (Charlebois et al. 2024).

Notably, the study found common trends of high-value industry partnerships as well as observable differences between the approaches taken by public and private organisations. Additionally, the widespread use of QR codes and blockchain technology became a major trend in all member nations, highlighting their critical role in improving transparency and traceability (Charlebois et al., 2024).

The comparative analysis of digital traceability in agri-food supply chains across OECD member countries has underscored several strengths and areas for improvement. The ability of digital traceability systems to improve supply chain transparency and food safety is one of their main advantages. However, the study also identified areas where the implementation of digital traceability systems needs to be improved. To guarantee the smooth integration and interoperability of traceability systems, these include the requirement for uniform laws and frameworks across nations. Initiatives to increase capacity are also urgently needed to inform supply chain managers, farmers, and producers about the advantages and practical applications of digital traceability (Charlebois et al., 2024).

The study acknowledges several limitations that could impact the generalizability and applicability of its findings. Firstly, the rapid evolution of digital technologies and their application in agri-food traceability presents a challenge in maintaining up-to-date and comprehensive data across all OECD member countries. Secondly, the diversity in economic, technological, and regulatory environments across these countries complicates the development of a one-size-fits-all approach to digital traceability. Lastly, the study’s focus on OECD member countries means that the findings may not fully represent the global state of digital traceability in agri-food supply chains, especially in developing and non-OECD economies (Charlebois et al. 2024).

There is an extensive amount of reports, documents, and studies carried out by the European Commission during the past years that have contributed to outlining regulatory policies both on the role of digitisation in agriculture and, more specifically, on food traceability.

In 2020, the study *Farmers of the Future* invited to build transformative resilience, highlighting the importance of networks, in particular, farmers’ connections with consumers and rural areas. In 2021, a participatory foresight process contributed to developing a long-term vision for “*stronger, connected, prosperous and resilient rural areas*” throughout the EU. Digital connectivity is part of the ensuing areas of action. In 2022, the Commission's strategic foresight documents set the direction of travel “*towards a green and digital future*”. Agriculture was part of the critical sectors explored through a deepdive process. In 2023, the study *Digital transition: long-term implications for EU farmers and rural communities*, carried out by the European Commission Joint Research Centre (JRC) in close collaboration with the Commission Department for Agriculture and Rural Development (DG AGRI), provided a toolkit aimed at supporting policymakers in their considerations of the digital transition process. An inclusive discussion of what these elements mean in a specific context and how they can be integrated into the actions taken by all parties can help create a common strategic perspective. The study builds on the previous JRC work on agrifood systems and rural areas, such as *Farmers of the Future* (Krzysztofowicz et al, 2020), *Long-Term Vision for Rural Areas* (Bock and Krzysztofowicz, 2021), *Concepts for a Sustainable EU Food System* (Bock et al., 2022), as well as *JRC Reference Scenarios* (Vesnic Alujevic et al., 2023) and the report *Towards a Green and Digital Future* (Muench et al., 2022). The study also considered the findings of two Horizon 2020 projects – DESIRA and SHERPA on relevant aspects of digital transformation in rural areas (DESIRA H2020 project: <https://desira2020.agr.unipi.it>; SHERPA H2020 project: <https://rural-interfaces.eu/>).

The role of digitisation in agriculture in supporting the transformative process towards more sustainable food systems has been at the center of different studies and reports. As the transformation of the agriculture and food system is necessary to address society’s major challenges, the transformational aspect of policies is also becoming more relevant. Making policies transformational requires a good understanding of the direction the transition should take and a multi-faceted policymix of instruments addressing multiple stakeholders in multi-level governance. Policies supporting digitisation in agriculture should focus on the transformational potential of these technologies, taking into account the purpose, values, and principles set out in the vision framework. Policy can play an important role in shaping the digital transition of agriculture. This foresight study puts forward a robust framework for a comprehensive EU digital transition strategy (JRC-European Commission, 2023).

Specifically, N.B. Kondratieva’s paper provides an examination of the problems of digital transformation in agriculture in Europe (Kondratieva, 2020). In this paper, the author identifies the framework documents and

areas of discussion on the development of the digital strategy of the European Union in the agricultural sector. Taking into account the successful practice and opinions of the competent centers, an idea was formed about the principles and ten areas that are covered by supranational assistance, which form a kind of *Decalogue of agricultural digitalization*. The author notes that the regulation of digital transformation in agriculture is due not so much to the need to increase the economic efficiency of business processes, but rather to the intention to facilitate the control of their compliance with the criteria of climate neutrality and inclusiveness. The digitalization strategy of the *Common Agricultural Policy* (CAP) brings its goals closer to those of sustainable development (Kondratieva, 2020).

The tides of technological innovation that are reshaping the global landscape have demanded a recalibration of the EU’s economic strategy. The EU is facing a stark reality: its digital competitiveness lags global leaders like the US and China. The European Commission’s 2023 Joint Communication on a *European Economic Security Strategy* recognises this, proposing a three-part approach: promoting competitiveness, protecting against risks, and partnering with like-minded countries (JOIN/2023/20 final). Market leaders across the different technology areas, in addition to two EU industry associations, consulted to produce the report, were asked to evaluate proposed measures to enhance EU competitiveness and security. Among the report’s main findings, the EU lagging in most critical technologies, the shortfall in public and private investment across several critical technologies, including artificial intelligence (AI), and the tech talent shortage represent worrying signals that require targeted responses. Broadly, the European Commission’s Economic and Security Strategy largely prioritises measures aimed at protecting the EU’s economic security, rather than promoting industry competitiveness or partnering with allies.

The history of food traceability has already been extensively traced by several authors, including Montet and Dey (Montet and Dey, 2018).

Instead, in recent years, a significant number of academic studies have appeared with a focus **on the functioning and sustainability of the Food Supply Chain (FSC), particularly those related to its segment of wholesale and retail activities** (Negruè, 2022; Bancat et al., 2022; Rizou, 2020) showing a lot of shortcomings primarily in the segment of food safety and security, confirming that the traditional FSC is not ready to mitigate all shocks and uncertainties that appear in the market, and pointing out that the flow of information between participants is not at a level that will enable supply chain management to react in time in terms of adequately finding alternative supply channels for raw materials and final products (Zoric et al., 2023). These studies highlight the food supply chain's lack of robust digitisation, non-transparency, and poor cross-channel activity coordination. All of this indicates that the traditional food supply chain needs to be changed into a contemporary digital chain that uses cutting-edge IT technologies (blockchain, IoT, etc.) (Zoric et al., 2023). In particular, some findings showed that critical indicators like the coordination and transfer of information, external elements, and chemical and microbial contamination can have significant negative effects on the sustainability and functionality of the FSC in the segment of wholesale and retail activities and that the digitisation process significantly affects critical indicators, except for external factors (Zoric et al., 2023).

According to the *World Economic Forum* (WEF), “*food plays a central role in human societies and is essential to the well-being of people and the planet. But a fundamental transformation is needed to meet the aspirations of an inclusive, efficient, sustainable, nutritious, and healthy food system*” (WEF, 2019: 6). Furthermore, WEF argues that the application of modern information technology is a critical enabler for food supply chain development, especially food traceability. As such, a digital transformation will have a significant impact on global agri-food sectors and create new business opportunities. One can envision a future business-driven data architecture encompassing the entire agri-food ecosystem. In this scenario, a smallholder farmer is holding a digital device with information feeds and alerts from multiple on-farm technologies and cloud-based service providers. The small-scale farmers essentially have a portable decision-support tool that democratises technology by making it accessible and affordable. A wide range of revolutionary and potentially disruptive technologies are implemented in food supply chains, ranging from mobile devices to Internet of Things (IoT) devices on machinery, cars, and farm animals (Keogh et al. 2020).

Food traceability systems, their design, implementation, and evolution are influenced by a combination of different drivers, including regulations and the need to capture information on food safety, quality, and integrity, worker welfare, animal welfare, environmental protection, and sustainability requirements (Islam & Cullen, 2021). Islam et al. (2022) differentiate between internal food traceability systems that operate within an organisation and external food traceability systems that operate outside of the organisation. These internal food traceability systems need to link together (interoperability), they argue, to create a chain of custody for a product. **The benefits and barriers associated with food traceability systems have been collated widely, analyzed, and discussed through different sources**, primarily (Kowalska et al. 2024).

Analysis & criticism: what are the pros, cons, and lessons learnt from each individually and as a whole when put together?

The literature review provides an insight into existing research in this field. Synthetically, food traceability is a key process of a sustainable and efficient supply chain. Over the years, Europe (and not only) has framed, through different regulations, the process that makes it possible to track and document the history of a particular food product, from its production and transport to its arrival at the consumer. Among other things, this has made it possible to quickly identify the source of problems in the event of food contamination or the outbreak of foodborne illnesses, ultimately enabling the quick withdrawal of unsafe products from the market. In addition, implementing food traceability has enhanced transparency throughout the entire food production and delivery process.

New technologies can bring numerous benefits to food traceability for all the stakeholders of the food supply chain. Farmers and producers can document the source of their food and confirm they have followed a set of standards. Manufacturers and distributors can digitise on secure, unalterable ledgers. Retailers can gauge the freshness of products, communicate authentically with consumers, make business operations more efficient, and reduce food waste. Consumers can scan food products and quickly access relevant information online (EIT Food, 2019).

Digital traceability can alleviate and reduce many of the agrifood sector's most pressing risks. For example, these technologies can streamline corrective actions by quickly identifying issues as well as reduce risks associated with food safety and food fraud (WEF, 2019) by making it easier to track the route of a problem. They can also optimise the use and reuse of materials or resources, boosting the sustainability and cost-efficiency of the food supply chain. It is estimated that farmers who transition to using digital technologies yield around \$10 in benefits for every \$1 spent (Fabregas, 2019). Digital traceability technologies can also certify products to ensure only fair and sustainable goods make it to market - and that the authenticity of these products is communicated to the consumer (WEF, 2019).

The *United Nations Global Compact* defines supply chain sustainability as the "*management of environmental, social and economic impacts, and the encouragement of good governance practices throughout the lifecycles of goods and services*" (UN Global Compact Office and BSR, 2015). This means that supply chain policies, programmes, and traceability technologies can therefore offer key opportunities for agrifood businesses to scale up their sustainability practices and contribute to the advancement of the UN's Sustainable Development Goals (SDGs) (WEF, 2019).

Despite these clear benefits, there are often concerns about implementing these technologies. For food supply chains to become truly traceable and for the benefits to be felt by all within the food value chain, the use of these technologies must become universal. With barriers such as price, accessibility, and acceptance, the uptake of key digital solutions such as blockchain - a decentralised system for recording and protecting transactions and data - has been limited due to a lack of "technological maturity" (FAO, 2020). Other factors could include reluctance from smaller businesses or farms in developing countries, for example, who view the digitisation of processes as costly and complicated ("New research sheds light on the reluctance of farmers to adopt new technologies." ScienceDaily, ScienceDaily, 2 October 2020. <www.sciencedaily.com/releases/2020/10/201002141915.htm)

There are also over 10 million farms in the EU (Eurostat, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agriculture_statistics_-_family_farming_in_the_EU#:~:text=There%20were%2010.5%20million%20farms,value%20of%20the%20agricultural%20output.). How can these technologies be rolled out so that all farms, producers, retailers, manufacturers, and officials have universal access to them, and all complex supply chains follow the same standards of traceability?

This last consideration raises a relevant point of the analysis, that is, the impact of digital traceability systems (traceability requirements, labeling standards, and risk assessment procedures) on the competitiveness of the European agri-food sector, and more generally on the functioning of the system itself, both for consumers and for all businesses. The agri-food industrial ecosystem includes different actors in the food supply chain, such as farmers and fishers, the food and drink industry, food retail, and catering. The ecosystem is a significant part of the EU's economy. For example, the food and drink industry generates 4.6 million jobs and provides an added value of €227 billion. Small and medium-sized enterprises (SMEs) account for more than 99% of businesses in the ecosystem (https://single-market-economy.ec.europa.eu/sectors/agri-food-industrial-ecosystem_en#:~:text=outside%20the%20EU,-,Competitiveness,the%20need%20for%20more%20competitiveness.&text=An%20important%20EU%20wide%20initiative,the%202014%20and%202019%20reports.

Moreover, there seems to be a lack of strategy (and decision-making) among policymakers, professionals, and even stakeholders on how to face these impacts on the supply chain. Of course, the EU agri-food sector is known for its high-quality, healthy, and safe food; however, its relative competitiveness has decreased compared to other world food producers, particularly in terms of slower growth in labor productivity and added value. The EU's global trade balance in agri-food products remains positive, with the EU being a major exporter.

The EU Industrial Strategy highlights the need to accelerate the green and digital transitions of the EU industry (https://single-market-economy.ec.europa.eu/industry/strategy_en). As part of these programmes and initiatives, the Commission has proposed to co-create, together with industry, public authorities, social partners, and other stakeholders, transition pathways for the different industrial ecosystems. The Transition pathway for the agri-food industrial ecosystem was published in 2024 (EU Commission, DG for Internal Market, Industry and Entrepreneurship, and SMEs 2024). This document includes a set of actions to support the green and digital transition of the agri-food ecosystem, while also improving its resilience. Specifically, the set of prioritised technologies ready to enter the market includes: artificial intelligence, automation and robotics, digital monitoring systems, the Internet of Things and big data, and traceability (EU Commission, DG for Internal Market, Industry and Entrepreneurship and SMEs 2024).

Research & Innovation (R&I) is essential in steering the green and digital transition of the EU's agri-food ecosystem and the global transition to reach the UN SDGs. Unfortunately, it is known that despite the growing (R&I) investments in agrifood, the EU food and drink industry invests less in R&I than several competitors across the globe (FoodDrinkEurope, 2023). Stakeholders have also highlighted issues such as dispersed research, lower investments, and a need for an improved innovation culture for sustainable progress (EU Commission, DG for Internal Market, Industry and Entrepreneurship, and SMEs 2024).

Moreover, the fundamental role of social dialogue committees in the policy-making process is highlighted at the EU and national levels. The social and economic partners are suited to effectively contribute to eventually reformulating and implementing policies that can support the sector (EU Commission, DG for Internal Market, Industry and Entrepreneurship, and SMEs 2024). Despite this commitment, which led to the launch of consultations through workshops and survey activities, a complex framework of the state of the art isn't yet provided. Perhaps what seems to be clear enough is that measures or policies that seemed reasonable and targeted months ago are less so today.

Research gap: What is the novelty or hypothesis worth investigating further?

This issue represents exactly the research gap, highlighted by the literature review, where further research is needed, contributing to the advancement of knowledge. The novelty worth investigating consists, on one hand of the necessity and opportunity of analyzing the European food safety policies, starting from the perceptions and concerns expressed by businesses, farmers' associations, unions, and consumers, on the impacts of digital traceability systems, and on the rules and procedures that govern the functioning of the food supply chain. This hypothesis will provide different discourses on food digital traceability, eventually updating the issues, barriers, and challenges that can enable its implementation.

The analysis of the *Strategic Dialogue on the Future of the EU Agriculture* provides the feasibility/researchability of the research topic, ensuring measurable and observable results that will be evaluated and discussed.

The results provide a set of recommendations useful for policymakers, professionals, and stakeholders of the agri-food sector.

3. Methodology

The research process adopted in the paper follows two steps.

The first one aims to collect through primary sources such as studies, reports, documents, regulations, key figures on food traceability issued by the European Commission, European Parliament, and National Policies, and secondary sources such as workshops, steering committees, reviews and press releases, reports, and documents on the topic issued by Associations, Unions, and other entities of the agri-food sector and Universities, the set of narratives and discourses on food safety and digital traceability regulations carried out during the recent years to frame the positions, simply listing the issues raised.

The second one focuses on the analysis of the final report of the *Strategic Dialogue on the Future of EU Agriculture*. Specifically, the analysis emphasises the parts of the report targeted to technology and traceability in food safety.

Both of the steps of the research approach embrace the tool of critical discourse analysis. The paper conducts a discourse analysis of documents and reports focusing on food safety and traceability to identify the concerns expressed by the stakeholders, and the market drivers for the enhancement of digital traceability systems. Discourse analysis is a collective name for some scientific methodologies for analysing semiosis, namely how meaning is created and communicated through written, vocal, or sign language (Cummings et al., 2020). It focuses on the relationship between discourse and other elements of social practices, such as policymaking.

Policy content analysis is primarily “used to compare different perspectives on the same topic” (Pierce, 2011) by different policies. Some authors view discourse analysis as a methodology rather than a mere method, to emphasize the potential of the technique to understand “discourse and its role in constituting social reality” (Phillips and Hardy 2002, p. 9). It is important here to notice that this study has the limitation of being exclusively qualitative. Hence, the choice not to gather quantitative data has been made as qualitative discourse analysis seemed the best methodology to answer the research question that led to this research (Minotti & Zagata, 2020).

In particular, the use of discourse analysis helps to understand how key concepts come about, why they have a specific meaning in that context, how some discourses draw from and influence other discourses, and how these discourses are constructed through diverse texts (Phillips and Hardy 2002, p. 8). This paper follows the history of regulatory frameworks, which tried to understand if the “policy layering on sustainable policy reform” (Daugbjerg and Swinbank, 2016) was going in the direction of a paradigm shift or was following an “evolutionary reform” (Buckwell, 2015).

Critical discourse analysis has been widely used for policy analysis (Hornidge 2011; Langan 2011; Fairclough 2012) because it can be employed to identify dominant, marginal, oppositional, or alternative discourses within

policy texts, such as policy documents and speeches. In the case of this research, the visions for the future of the EU food safety, and, specifically, the adoption of food traceability systems.

According to Cummings, although critical discourse analysis is a very useful tool for policy examination, it remains complex to apply for two reasons. First, it is described in the literature in a specialist, academic way, and second, its application is not explained in clear steps.

The strengths of the critical discourse methodology are twofold. First, it allows for analysis of policy documents by revealing their inner biases and claims in a systemic, structured way, revealing their hidden preoccupations and how they reflect different discourses: dominant, marginal, oppositional, or alternative. Second, the methodology is also intrinsically activist because the final stage involves the identification of new discourses, narratives, and arguments that can counteract ‘social wrongs’ in the current, dominant discourse (Cummings et al., 2020).

The critical discourse analysis focuses on discourses and narratives. What is discourse? Parker considers discourse: ‘a system of statements which constructs an *object*’ (1990: 187). Discourses are also subject to institutions, power relations, and ideology (Parker 1990).

The policy is considered as text. The first step in undertaking critical discourse analysis is to take a closer look at the concept of semiosis. Although semiosis relates to written, vocal, or sign language, in the analysis of policy documents, we are looking at texts. Policy documents are not formed by chance. As discussed by Fairclough, they are ‘... *formed, disseminated and legitimised within complex chains and networks of events* (committee meetings, reports, parliamentary debates, press statements and press conferences, etc.)’ (Fairclough 2013: 244-245)

As Freeman and Maybin explain:

Policy documents, through their writers and editors, may state truths - or they may suppress, elide, or embellish them. The process of writing a statement or briefing, for example, is often a matter of sorting, selecting, and ordering the many truths it might contain. It matters very much, therefore, just who is allowed or tasked to write what and by whom, and this testifies again, above all, to the real or assumed power of the document itself. (2009: 7).

Not only are the contents of policy documents subject to political processes when they are being written, but Hornidge (2011) also considers that they can be used to legitimize already existing government policies by presenting a vision of the future. In making this point, she considers discourses around the knowledge society:

‘... the vision of a self-emerging knowledge society, therefore, acted as the basis for legitimising government programmes and activities towards the realisation of the envisioned future stage of development’ (2011: 4).

In this way, policy documents can be used to present an inspirational vision that convinces stakeholders of the need for action while ultimately also preserving the status quo, enshrined in the dominant discourse. Fairclough argues that ‘*dominant construals of the “new global order” have certain predictable linguistic categories*’ (2013: 247), namely that processes of change are divorced from social actors, history, time, and place; that statements are presented as truths; and that they are normative. This divorce from social actors, history, time, and place, the normative nature, and the presentation of truth are also aspects of policy documents that can be given attention during critical discourse analysis (Cummings et al., 2020).

According to Fairclough (2005), this methodology is transdisciplinary because it assembles diverse disciplinary resources, without expecting or seeking any substantive change as a result and without confronting ‘thorny theoretical and methodological problems involved in transcending theoretical boundaries’ (Fairclough 2005, 53). However, we would argue that this type of critical discourse analysis represents a particular interdisciplinary approach. Based on the transdisciplinary tradition within which the authors are located, transdisciplinary research is characterised by ‘*a focus on real-world problems, involvement of multiple*

stakeholders, integration of different forms of knowledge, and crossing boundaries between disciplines and between science and society’ (Cummings, Regeer et al, 2013).

The evolution of discourses on the EU digital food traceability strategy, from the EU Regulation (EC) No 178/2002, which established the European Food Safety Authority and laid down general principles for food traceability, to the recent *Vision on EU Food and Agriculture*, that has gathered the results and recommendations contained in the final report of the *Strategic Dialogue*, is analysed comparing the findings of the report *Innovation with a Purpose: Improving Traceability in Food Value Chains through Technology Innovations* issued by the World Economic Forum (2019) supporting the *System Initiative on Shaping the Future of Food* with the conclusions of the *Strategic Dialogue*.

In 2017, the *World Economic Forum* launched the Innovation with a Purpose Initiative to support the sector’s investment in technology solutions to meet these systemic challenges. The following year, the Forum published a report on this topic, *Innovation with a Purpose: The Role of Technology Innovation in Accelerating Food Systems Transformation*, which identified the ‘Transformative Twelve’: twelve technologies with the potential to enhance food systems. Traceability, which builds on several of these transformative technologies, provides a foundation to address many of today’s food-systems issues in addition to contributing to the advancement of the *Sustainable Development Goals* and has potential throughout developed and developing markets. In 2019, many of these technologies were already beginning to disrupt food systems and drive new business models. However, such a transformation of global food systems at the time, and much more nowadays, presents risks, such as the potential exclusion of small-scale producers. Therefore, multistakeholder collaborations focused on inclusivity and innovation will be vital to optimizing the potential benefits of traceability.

Traceability, according to WEF, is not a silver-bullet solution, but it holds distinct promise in helping drive food-systems transformation. It has the potential to strengthen inclusivity and empower small-scale producers with improved market visibility and access to new services and resources. However, to ensure that its potential impact is maximized, the traceability agenda must focus on ways to introduce inclusive scaling, particularly concerning underserved communities.

The WEF report outlines **four priority areas** to establish inclusive pathways to scale.

1. An economic model to support the financing of capital expenditures and ongoing operational costs. Multistakeholder collaborations focused on scaling commercially viable solutions, combined with catalytic financing and policy incentives, can support small-scale producers. This enables them to adopt emerging technologies that would otherwise necessitate high capital investments and operational costs.
2. Investment to overcome infrastructure gaps and develop more robust technology and lower-cost solutions. Ongoing technological development to drive down costs and support the efficient adoption of traceability solutions will require close collaboration between providers, users, government, and civil society to advance as quickly as possible.
3. Development of clear, consistent, and globally harmonized standards for data collection, governance, ownership, and sharing. Without alignment, traceability could inhibit scaling by imposing inconsistent standards and requirements that prove burdensome, particularly for small-scale producers. Neutral third-party organizations will play an important role in bringing stakeholders together to align on clear, consistent, and harmonized standards.
4. Training on traceability requirements and access to advisory services. Helping small-scale producers make the appropriate changes to comply with traceability requirements will entail effective communication of aligned standards. This will need to be paired with training and advisory services on how to comply with these standards.

Creating a transformation agenda that accelerates progress toward achieving a healthy, nutritious, sustainable, efficient, and inclusive food system will require unprecedented collaboration within and between

organizations, initiatives, and stakeholders. Depending on a stakeholder’s role in the value chain, the specific traceability challenges and opportunities it encounters will differ. Mutual understanding of these opportunities, challenges, and enabling priorities will underpin effective collaboration.

Governments can incentivize traceability and support adoption. Technology companies have the potential to further develop the transformative traceability technologies needed to reduce costs, improve delivery, and maximize efficacy. Retailers can take the lead when convening with other stakeholders to build the right multistakeholder collaborations to bring about transparency. Agribusiness companies can support the application of traceability for food value chains by coming to the table with an open mind, considering new business opportunities, and pushing forward on existing commitments. Food producers, especially small-scale producers, are at risk of being left behind; they should identify clearly what they need to ensure traceability will help their operations. Civil society and system leaders can play the role of convener to ensure all stakeholders have a chance for input when creating standards and requirements.

Traceability offers one example of how the ‘Transformative Twelve’ can be applied to address food-system challenges and bring significant positive impacts to both more mature and emerging markets. As it develops, traceability will enable broader opportunities, though this collaboration should be built on a shared vision and executed with a recognition of the mutual benefits of partnership. To achieve traceability’s full potential, stakeholders will need to come together to enable emerging technologies to scale inclusively and to install a broad ecosystem agenda supported by appropriate standards.

The priority areas mentioned in the WEF Report represent technology-enabled end-to-end traceability in food value chains, coupled with multistakeholder collaboration, which has the potential to fundamentally improve food systems. They have been selected for comparison because they are emblematic of the mindset and they are both communicative contents, which made them suitable for discourse analysis.

The results of the discourse analysis of the *Strategic Dialogue* related to the four highlighted areas are examined and discussed, and finally, conclusions will be drawn.

4. The Strategic Dialogue on the Future of EU Agriculture

Purpose of the Dialogue

Launched in January 2024, the *Strategic Dialogue on the Future of EU Agriculture* is a new forum that aims to shape a shared vision for EU farming. The *Strategic Dialogue* brings together key stakeholders from across the whole agri-food chain, including farmers, co-operatives, agri-food businesses, and rural communities; as well as non-governmental organisations and civil society representatives, financial institutions, and academia.

Professor Peter Strohschneider was appointed as chair, based on his longstanding experience, notably as chair of the Federal government of Germany's "Commission for the Future of Agriculture".

Developing a joint understanding

The Dialogue is crucial for developing a joint understanding of the future EU farming and food system. It tackles the following challenges and opportunities:

1. How can we give our farmers and the rural communities they live in a better perspective, including a fair standard of living?
2. How can we support agriculture within the boundaries of our planet and its ecosystem?
3. How can we make better use of the immense opportunities offered by knowledge and technological innovation?
4. How can we promote a bright and thriving future for Europe's food system in a competitive world?

Specifically, question number 3 constitutes the area on which the analysis focuses.

The Dialogue is an opportunity to hear the perspectives, ambitions, concerns, and solutions of farmers and other key stakeholders from across the agri-food chain, to find a common ground for the future of the Union’s agri-food sector.

Strategic Dialogue Report

On 4 September 2024, President of the European Commission Ursula von der Leyen received the final report of the Strategic Dialogue on the future of EU agriculture.

Participants

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The final report

The report describes a shared direction of a journey for this transformation in a vision that outlines the contours of European agri-food systems in ten to fifteen years. With its recommendations, the *Strategic Dialogue* acknowledges that the transition of the agri-food systems inevitably implies conflicting interests and complex trade-offs that can only be resolved through compromise. This requires a stable starting point and shared foundations and objectives to steer the sector’s transition which can be subsumed into guiding political principles. Among them, guideline number 8 of the *Strategic Dialogue* explicitly mentions technology:

“The opportunities of technology and innovation should be leveraged to support the transition towards more sustainable agri-food systems.”

In addition, it emphasises:

‘Innovation —including social innovation such as inclusive governance mechanisms— and technologies can play an important role in facilitating and accelerating the transition to more sustainable agri-food systems and reaching its multiple objectives. They can help support the sector’s competitiveness and contribution to food security while bringing sustainability improvements and businesses.

Innovation needs to be inclusive, accessible to all stakeholders in the agri-food system, scalable, and replicable. This can be achieved also through open innovation systems or using an open-source approach. A system-based approach to innovation is needed to encompass the complexity of agriculture and food systems.

A long-term strategy of agri-food policy in Europe must be supported by an enabling regulatory approach and predictable, science-informed decision-making processes to encourage investment in innovation and to successfully translate and disseminate knowledge into sustainable products, services, and practices.

Relevant knowledge, innovation, and technologies need to become accessible and applicable for farmers and the entire agri-food sector much faster than in the past. At the same time, their risks need to be thoroughly

assessed before their introduction, paying due regard to the precautionary principle and potential effects on social, environmental, and economic sustainability.

Knowledge and innovation need to be developed to be applicable on the ground and adapt to the local social, environmental, and economic context. The development process should always involve end users and take into account their specific needs and the context in which they operate. Such participation in the development of new solutions is essential to strengthen alliances and knowledge exchange among many stakeholders and to ensure collaboration. Farmers must therefore also have access to a sufficiently developed network of independent advisory services (Strategic Dialogue, 2024).

Achieving environmental objectives, resilience, and competitiveness for agri-food systems in Europe requires new approaches to farm and food policies. To this end, the members of the *Strategic Dialogue* addressed some recommendations. As regards the food labeling:

‘The European Commission should conduct a full review and, where necessary, update EU food labeling legislation to ensure consumers are provided with trustworthy, comprehensive, EU-wide, science-based, comparable and transparent food labeling that is easily accessible, understandable, and usable and allows for informed choices about key sustainability dimensions of food, including animal welfare while considering the feasibility for operators. The use of digital means could support the provision of voluntary information to consumers (Strategic Dialogue, 2024).

Up to addressing a “*Better access to and better use of knowledge and innovation*”:

‘Innovation, technology, and knowledge play a key role in the transition of the agri-food sector. To fully leverage this potential, generation, access to, and better sharing of knowledge and skills must be facilitated. Independent advisory services will be crucial in that process. More public-private partnerships and increased investments in research and innovation are vital. To ensure that innovation can benefit food system actors, regulatory procedures need to be streamlined, and digital opportunities promoted. The role of social innovation must be acknowledged and supported’ (Strategic Dialogue, 2024, 85).

The sustainable transition of the agricultural and food system, as repeatedly emphasized in this report, is a task for society as a whole. Mastering this task requires the effort of all areas and subsystems of society. In this context, research, technologies, and innovations are also of paramount importance. They may include, inter alia, satellite and drone imagery, artificial intelligence, and process automation. In particular, digitalization can improve the management of sourcing and trade flows, but it must be embedded in democratically responsible governance mechanisms, agency, and knowledge systems. Whilst new technologies have benefits, it should be noted that they are rarely without side effects and that they can entail socio-economic risks and challenges, such as, e.g., changes in the public sphere, job losses, new skills requirements, or a so-called digital divide.

Agri-food innovations and innovation systems must be based on top-in-class science and research, supporting concrete product and/or service development. As food producers have intimate knowledge of the agroecosystems within which they operate, alignment with local knowledge as well as adaptation to local environmental and social conditions need to be taken into account in the innovation process. Careful and comprehensive consideration of the precautionary principle is equally essential. Lastly, innovation and the use of technology must be aligned with and guided by a long-term vision of agriculture and food systems in the EU. A clear direction of the trajectory will encourage investment in innovation and knowledge sharing and will ensure that new technological developments are targeted towards shared objectives.

This goal, according to the report, needs to be achieved by:

- **Facilitating access to and better sharing of knowledge and skills** - There is already a great deal of knowledge available that can help transition to fair, sustainable, resilient agri-food systems, but dissemination remains too limited. For producers, there is notably the need for access to independent expertise that disseminates agronomic knowledge across the EU and to training and technical support to effectively adopt new knowledge and enable the updating of sustainable practices. This also requires

a forum where producers and independent experts can share skills, experience, and knowledge. Therefore, access to and sharing of knowledge and skills must be improved in a way that includes and benefits all actors in the food chain. To achieve this, the European Commission, Member States, and agri-food actors should put in place well-funded, participatory knowledge systems for the rapid and effective dissemination and exchange of existing knowledge, best practices, skills, research findings, innovative techniques, and experience to enable the required transition. This also implies the establishment of institutional structures and organizational capacity to identify and deal with knowledge and skills gaps, overcoming obstacles to the transition. Furthermore, the above-mentioned actors should invest in agriculture-related education and food literacy to increase public and professional awareness of sustainable food systems, highlighting the benefits, risks, and trade-offs associated with different approaches. Specifically addressed to the European Commission is the Strategic Dialogue’s recommendation to evaluate and revise, where needed, the design, governance, and functioning of farming extension and advisory services, aimed at providing farmers and food producers – in an inclusive way – with access to free and independent expert guidance, technical assistance, and training programs. It also should strengthen the implementation of *Agricultural Knowledge and Innovation Systems (AKIS)* within independent farm advisory services (Strategic Dialogue, 2024, 84).

- **Increasing investments and partnerships in Research & Innovation** - Increased funding for education on agriculture and food systems, lifelong learning, and independent advisory services is needed. These programs and services will play a vital role in guiding the new generation of farmers in their efforts to farm sustainably. Funding lines are also needed to encourage social innovation and experimentation at the local level, for instance, in the development and implementation of local food policies. To achieve this, the European Commission and EU Member States should better leverage existing funds to facilitate the effective dissemination of skills and safe technological advancements. They also should support and strengthen innovation hubs and experimental settings across different regions within the EU, where farmers, food business operators, technology developers, and public authorities can collaborate to pilot and assess the effectiveness of new or existing technologies and knowledge while showcasing these in real-life settings. Member States are requested to increase EU funding for RDI initiatives specifically on sustainability-focused agri-food technologies and innovations, allocating a higher percentage of the Horizon Europe to projects aimed at developing and testing new technologies and innovations for sustainable agriculture, food production, and distribution. Agri-food systems actors, research institutes and universities, Member States, and the European Commission should work towards establishing and strengthening public-private partnerships between research institutions and the private sector to generate investment, facilitate knowledge exchange and collaboration in developing cutting-edge solutions for the agri-food sector, ensuring adequate public funds are dedicated to basic research. They should also support the development of networks of organizations, communities, enterprises, and individuals within which improvements are generated and spread. For all these initiatives, the multi-actor approach will help create opportunities for co-learning and collective action that support sustainable transitions. To that end, the European Commission should introduce public-private partnerships in cluster 6 of the *Horizon Europe programme* (Strategic Dialogue, 2024, 85).
- **Streamlining regulatory procedures for the access to market of new technologies and innovations** - Currently, the evaluation and market approval of some new technologies and innovations in the EU is sometimes an issue. Streamlining and accelerating EU administrative and regulatory processes and procedures of agri-food innovations is needed, while maintaining a robust and comprehensive risk assessment based on the precautionary principle. Securing a healthy and sustainable food system for the future in Europe requires us to marry sustainable innovation with the promotion and preservation of our positive culinary heritage. To achieve this: 1. The European Commission, the Member States, and the European Parliament, together with EFSA, should work together to identify faster regulatory pathways for innovative products and processes focused on increased sustainability while respecting the need for robust risk assessment; 2. The European Commission and Member States, moreover,

should aim to harmonize standards and certification processes across EU Member States to reduce barriers to market entry for innovative agri-food products and technologies, ensuring a level playing field, enabling seamless adoption and scaling across different regions (Strategic Dialogue, 2024, 86).

- **Responsibly using the opportunities of digitisation** - Food systems are becoming increasingly digital. Today, in parts of Europe, crops, animals, and trucks are more and more monitored by smart sensors, satellites, drones, and machinery equipped with GPS and cameras. The result is an abundance of data with unprecedented potential to support smarter decisions by businesses or consumers, to trace food integrity, and to support public decision-making by governments. The shift towards digitalization transcends mere technological advancements; it entails profound social, cultural, economic, and institutional changes. Data utilization can offer significant benefits and support the benchmarking system and data exchange in agri-food systems. It also raises concerns about fairness, quality, and privacy. Hence, robust data governance frameworks and their proper implementation are essential. The European Commission and Member States should also provide lifelong training in digital skills, literacy, and information on digitalization for farmers and workers in food systems in general, paying special attention to availability in rural areas. Overall, robust monitoring and evaluation mechanisms need to be established to assess the impact of digitalization initiatives in the agri-food sector. Data on adoption rates, productivity gains, environmental outcomes, and socio-economic results should be collected to inform future policy decisions (Strategic Dialogue, 2024, 86-87).

In conclusion, regarding question number 3 at the core of the *Strategic Dialogue*, the contributions can be thematically clustered around three central aspects: **research and development (R&D) of innovation; uptake of and access to technologies; and societal acceptance of innovation** (Strategic Dialogue, 2024, 104).

Concerning R&D, several stakeholders stress the need for an enabling regulatory framework to encourage innovation, including a clear, long-term vision and more efficient authorisation processes. At the same time, some stakeholders also warn that any technology entering the market must be safe and that risks need to be thoroughly assessed in advance. In addition, increased funding for R&D, from both public and private sources, is frequently mentioned by stakeholders. Lastly, some stakeholders call for more strategic public-private partnerships to accelerate and more efficiently target innovation processes.

Regarding the uptake of innovation and technology, the need for derisking investments in innovation is emphasised, including through risk-sharing mechanisms and financial incentives. Several stakeholders also point out the need for capacity and skill-building to enable the use of technologies. Frequently mentioned tools are knowledge sharing through peer networks and high-quality advisory structures. The importance of applied innovation, co-developed with the end users, is underlined. Stakeholders frequently stress the need to make innovation accessible, especially to small-scale producers, and draw attention to the significant role of improved digital infrastructure in rural areas to enable this.

Societal acceptance of innovation is a further-mentioned issue. Some stakeholders call for information and education programmes to raise awareness of the potential benefits of innovation among consumers. Stakeholders’ positions on these vary from calls for faster approval to more hesitant reminders of the potential safety risks of these technologies, including dependencies, and objections to certain specific technologies. Lastly, some stakeholders point out that not only innovation but also existing, traditional knowledge needs to be mobilised.

Regarding the overall approach to technology and innovation, some stakeholders stress that it should not be regarded as a “silver bullet” solution but should be treated as complementary to more systemic transformations of agriculture and the food system. Some also underline that innovation need not always be technical and that the role of social innovation needs to be considered.

Seen in the light of this paradigmatic innovation, the *Strategic Dialogue* shows a twofold result.

The first is the final report presented, whose parts related to traceability and technologies have been briefly presented above, and represent an important step on the way to economically profitable, environmentally sustainable, and socially responsible agriculture and food systems in the European Union.

The second result of the *Strategic Dialogue* is the emergence of a new culture of engagement between the members, which makes it possible to relate and balance the different points of view and interests of the various stakeholders in the entire sector, confirmed not only by the conclusions but by the over seventy-two contributions submitted to the Chair of the dialogue by farming organizations, agricultural trade organizations, agricultural input organizations, food processing and manufacturing, retail and wholesale, NGOs, multi-stakeholder coalitions, and others (Strategic Dialogue, 2024, 101).

The confirmation of this second added value lies firstly in the setting up by the European Commission of the *European Board on Agriculture and Food* (EBAF), taking up one of the recommendations of the final report of the *Strategic Dialogue on the Future of Agriculture*. Secondly, in the provision of high-level advice to the European Commission to inform the strategy policy development for the *Vision for Agriculture and Food* that was presented in February 2025 by the European Agriculture Commissioner Hansen, under the guidance of President von der Leyen. The document outlines a vision for 2040 and guides future policy discussions in a broad set of strategic issues for agriculture and food, including the direction of travel for the future CAP.

5. Results and discussion

The critical discourse analysis of the *Strategic Dialogue* is conducted through a comparison with the four priority areas outlined by the *World Economic Forum* (2019).

Below in Table 2 is the evidence of the comparison as far as the discourse analysis.

Table 2 Representation of the comparison of discourse analysis

Priority Areas WEF	Strategic Recommendations	Dialogue’s
1. Supporting the financing of capital expenditures and ongoing operational costs.	Derisking investments in innovation is emphasised, including through risk-sharing mechanisms and financial incentives. In addition, increased funding for R&D, from both public and private sources, is frequently mentioned by stakeholders.	
2. Investing to overcome infrastructure gaps and develop more robust technology and lower-cost solutions.	Warning that any technology entering the market must be safe and that risks need to be thoroughly assessed in advance. Lastly, some stakeholders call for more strategic public-private partnerships to accelerate and more efficiently target innovation processes.	
3. Developing clear, consistent, and globally harmonized standards for data collection, governance, ownership, and sharing.	No expressed evidence of harmonized standards. Stakeholders frequently stress the need to make innovation accessible and the tools knowledge shared.	
4. Training on traceability requirements and access to advisory services.	Several stakeholders point out the need for capacity and skill building to enable	

the use of technologies. Frequently mentioned tools are knowledge sharing through peer networks and high-quality advisory structures. The importance of applied innovation, co-developed with the end users, is underlined. Stakeholders frequently stress the need to make innovation accessible, especially to small-scale producers, and draw attention to the significant role of improved digital infrastructure in rural areas to enable this.

Source: authors' elaboration on WEF and Strategic Dialogue reports

Regarding points (1, 2, and 4), there is a substantial convergence in the discourse analysis, as far as what is outlined in the methodology section of the two documents. Regarding the points, there is a substantial convergence in the discourse analysis of the two documents, although the word traceability is not explicitly used in the *Strategic Dialogue* report. In this regard, it is noted that the report exclusively references food labeling.

Food traceability and labeling are complementary but not interchangeable terms. Food labeling and food traceability are interconnected practices crucial for ensuring food safety and informing consumers. Traceability allows for tracking food products throughout the supply chain, while labeling provides consumers with essential information about the product. Both play vital roles in identifying and managing food safety risks, responding to outbreaks, and ensuring regulatory compliance.

This constitutes a notation of no small significance. In consideration of the choice made upstream of the research, I am aware of the different characteristics (the commissioning institutions), the objectives (in the case of the WEF, the report constitutes a Purpose Initiative to support the sector's investment in technology solutions, the opposite of the *Strategic Dialogue* that seeks a shared vision among stakeholders) and of the approach (the WEF report was realised by non-independent advisors [McKinsey & Company], while the *Strategic Dialogue* report is the result of an open consultation among stakeholders), however, this constitutes a fundamental point regarding the strategy adopted by the European Union, which I will return to in the conclusions.

Regarding point 3, unlike the WEF report, in the *Strategic Dialogue*, there is no expressed evidence of the need to develop harmonized standards for data collection governance, ownership, and sharing. In this sense, the only point of substantial convergence lies in the stress expressed in the *Strategic Dialogue* by the stakeholders to make innovation accessible and the knowledge shared.

Aside from what has already been highlighted, the two documents are situated in completely different timeframes. The WEF report is from 2019, while the *Strategic Dialogue* one is from 2024. It is a period marked by the 2020 pandemic and its global effects, and above all, by the instability and the spiral of rising costs and food prices triggered by the conflicts in Ukraine first, and in the Middle East later. Additionally, it is necessary to consider that in 2024, elections were held for the renewal of the European Parliament, which were preceded months earlier by a mobilization of farmers and businesses of the agri-sector who denounced the unsustainable conditions determined, according to them, by the introduction of European measures and regulations, including the *Green Deal*.

The *European Green Deal* was introduced by the European Commission in 2019. It is an ambitious strategy to make the EU climate-neutral by 2050, with goals for reducing greenhouse gas emissions and transitioning to a circular economy. The introduction of the *Green Deal* and, in particular, its "*Farm to Fork*" (F2F) strategy

(2020) has raised a series of issues and challenges in the EU's food policies. The F2F strategy, which aims to make food systems greener and more sustainable, has raised concerns regarding its impact on supply chains and food availability. The goal of reducing the use of pesticides and fertilizers, along with changes in agricultural practices, could lead to lower yields and potential difficulties in food supply, especially during periods of food crisis. Accessibility concerns also relate to the economic sustainability of food products. The increase in production costs, due to changes in agricultural practices and the transition to renewable energy sources, could lead to higher prices for consumers, making food less accessible.

Concerns have also extended to the Implications for the agricultural sector: the F2F strategy involves significant changes in the agricultural sector, which could pose challenges for producers, especially small and medium-sized ones. The need to adapt to new regulations and agricultural practices could require investments and changes in infrastructure, putting the economic sustainability of many farmers to the test. Concerns also relate to the competitiveness of the European agricultural sector compared to third countries, which may not be subject to the same restrictions and environmental standards.

The transition towards a more sustainable food system is a complex process that requires a coordinated approach and collaboration among all actors involved, from production to consumption. The challenges also involve the concrete implementation of policies, raising consumer awareness, and the need to develop new technologies and agricultural practices. It is necessary to find a balance between environmental goals and economic and social needs to ensure a fair and inclusive transition.

The Commission's reluctance to openly address the economic impacts of the *Farm to Fork (F2F) strategy*, combined with limited engagement with key stakeholders such as farmers' associations and a brief public consultation, further blocked consensus. This has particularly affected critical proposals like the *Sustainable Use of Pesticides Regulation (SUR)* and the new *Sustainable Food Systems Framework*. Moreover, the internal divisions among the three Directorates-General responsible for implementing the strategy — DG SANTE (health), DG ENV (environment), and DG AGRI (agriculture) — stalled progress on many initiatives. The Strategic Dialogue sought to remedy these shortcomings by promoting a more inclusive and balanced discussion, and it has made a first step to restore cooperation, trust, and multi-stakeholder engagement, as demonstrated by the unanimous endorsement of the final report (Europe Jacques Delors, 2024).

After the European Parliament's negative vote on the *SUR directive on pesticides* in November 2023, what remained of the *Farm to Fork strategy* was a fragmented set of initiatives: an animal welfare package, soil monitoring legislation, gene-editing regulation, and revisions to reproductive material legislation. Nonetheless, the final report of the *Strategic Dialogue* does not reject the original ‘raison d’être’ of the Farm to Fork strategy – it signals that maintaining the status quo is no longer viable. There seems to be a broad agreement that only “*bold and swift action*” will ensure that EU food and farming remain “*economically profitable, environmentally sustainable, and socially responsible*.” The report also stresses the urgent need to shift our diets to advance towards sustainable food systems in Europe and unequivocally calls for a structural change in the *Common Agricultural Policy (CAP)* (Europe Jacques Delors, 2024).

The CAP 2023-2027 has faced criticism for failing to drive the necessary large-scale environmental transformation of the sector. Its complex governance system, reliant on National Plans intended to increase the flexibility of member states, has effectively led to the re-nationalisation of the CAP. Despite the introduction of such incentive mechanisms, the CAP has continued to support conventional farming methods and is not fit for purpose to meet current and future challenges facing the sector (Europe Jacques Delors, 2024).

These issues are useful to highlight that starting from 2024, but even before, positions aimed at crystallizing the situation have emerged in the European debate, advocating for a more cautious approach to the introduction of stringent rules and measures, which perhaps have also included the issue of food traceability.

This remark can be confirmed or not through the analysis of the recent trajectory of European decisions regarding digital food traceability systems. I'll investigate whether there have been any accelerations or decelerations over the reviewed period. The primary digital system used by the European Union to improve the

traceability of live animals and animal products both inside and outside of the EU is TRACES (Trade Control and Expert System). TRACES ensured that these commodities meet EU health and safety regulations by offering an efficient and transparent way to follow their travel through the use of cutting-edge digital technologies (European Commission, *The Future of Farming Is Here*, 2023). TRACES has revealed itself as an indispensable resource for government agencies, corporations, and individuals seeking to protect the health and safety of animals and food by offering up-to-date statistics and a vast database of information.

The timeline of the evolution of *TRACES* is very interesting to focus on. The *TRACES* classic system was established in 2004 to create a single, integrated computerised veterinary system, available to all Member States, for the recording of intra-Union movements and imports of animals and certain goods. In 2006, *TRACES* introduced the ‘import module’ for the issuance of official certificates to the European Union by non-EU countries. In 2013, *TRACES* grew significantly by accommodating over five modules and linking its data with other IT systems of the European Commission. In 2013, the platform expanded to the plant health domain as well. In 2017, the new *TRACES NT* platform was launched with a modern, more user-friendly interface and functionalities. *TRACES* also started to accommodate other departments’ modules, widening the scope of the system and strengthening the cooperation along the agri-food supply chain. In 2018, *TRACES* introduced the *PHYTO module* for the issuance of phytosanitary certificates by non-EU countries for consignments of plants and plant products imported into the European Union. In 2019, the Commission adopted the Regulation to lay down the rules for the functioning of the IMSOC and its system components (IMSOC Regulation EU 2019/1715). Additionally, the new Official Controls Regulation expanded the scope of *TRACES* to all categories of animals and goods subject to official controls at the border control posts of the European Union. The use of *TRACES* to issue the *Common Health Entry Document (CHED)* for animals and goods entering the European Union has become mandatory since December 2019. In 2022, all *TRACES* operations moved to the *TRACES NT* platform as the *TRACES Classic* platform was decommissioned. In 2022, over 2.3 million documents (~50% of the total) were signed electronically, replacing documents of paper format. In 2024, *TRACES* turned twenty years (https://food.ec.europa.eu/horizontal-topics/traces_en#the-traces-timeline).

TRACES constitutes an element of the European framework on food traceability, which, however, also includes other components such as the *Food Security Index*, the *AgriDataSpace project*, and the *Titan project*, all measures included in the *European Green Deal*.

Moreover, one of the major embedments in the EU framework is the *Food Security Index*. The *Global Food Security Index* was designed and constructed by the Economist Impact and is supported by Corteva-Agriscience. The *Economist Impact* updated the model annually to capture year-on-year changes in structural factors impacting food security. It lays a global foundation, and the EU has layered upon that by strengthening the agri-food sector with digital traceability. One such example of doing that is legally mandating an electronic certification for agri-food products when they are imported and exported. This system ensures that all food products adhere to regulatory standards and that all the information is found in a shared database. In tandem with these efforts, the *Joint Research Center of the European Commission* in 2019 developed a traceability and big data platform. This platform acts as a centralized resource for stakeholders in the agri-food sector across the EU and provides a plethora of tools and practices geared toward incorporating big data analytical systems into traceability systems, apart from the paperwork, too (Charlebois, 2024).

Furthermore, the *AgriDataSpace project* (2024) is a collaborative effort aimed at building a common database. These technologies had the potential to greatly improve traceability throughout the food supply chain, resulting in a more sustainable food system.

This sentiment is shared by the *Titan project* (2022-2026), an EU-funded initiative that intends to create a decentralized platform that promotes effective data sharing among various parties in the food supply chain. The project will achieve these objectives by developing fifteen innovative solutions, including DNA-based Rapid Detection Methods, Blockchain, AI, and IoT, that address key challenges identified in the *European Green Deal*.

All these measures and projects, included under the *European Green Deal*, since June 2024, are under observation and in some cases under review by the European Commission, especially regarding their impacts on the agri-food industry.

The same developments have been reported in the *Ecodesign for Sustainable Products Regulation*, which has introduced the *Digital Product Passport (DPP)*. In late 2023, the European Union implemented a new regulation requiring nearly all products sold in the EU to feature a DPP. This initiative aimed to enhance transparency across product value chains by providing comprehensive information about each product’s origin, materials, environmental impact, and disposal recommendations. The DPP is designed to close the gap between consumer demands for transparency and the current lack of reliable product data. The DPP is a digital document that collects and provides detailed information about a product throughout its lifecycle. This digital passport will include data on the provenance of raw materials, production processes, transport conditions, product shelf life, and how to dispose of or recycle them. The DPP is a step towards more responsible and transparent product management. By integrating advanced technologies such as blockchain, IoT, and artificial intelligence, DPPs have the potential to transform the way we manufacture, use, and recycle products, promoting a more sustainable and conscious future. A study published in June 2024, commissioned by the *Panel for the Future of Science and Technology (STOA)* of the European Parliament, suggested a realistic timeline to prepare businesses for the implementation of the DPP, suggesting full adoption in 2033. Of course, businesses need to ensure they understand the new requirements of the DPP and consider ways to progress the information transfer that will be required. Robust systems and processes will be crucial to gather, handle, and share the essential data. This may necessitate investing in new technologies for data management. The implementation of DPP in Europe is certainly one of the key initiatives of the *European Green Deal*. The European Commission will work before June 2024 to introduce regulations that make the adoption of DPP mandatory for several sectors, starting with electronic products and textiles, which are notoriously difficult to recycle and are responsible for significant environmental impacts.

After June 2024, the political and institutional guidelines for a revision of the *Green Deal* regulation, which erupted following the 2024 European elections, prompted the European Parliament and the Commission to adopt a different roadmap for the implementation of the regulations. Therefore, on this point, a substantial change in the discourse of the *Strategic Dialogue* is highlighted and thus confirmed, which is likely aimed at gathering suggestions and concerns expressed by the stakeholders.

The concerns regarding the monitoring of digitisation in agriculture are confirmed by the *2024 State of the Digital Decade report* that examines digital policy developments (<https://digital-strategy.ec.europa.eu/en/library/2023-report-state-digital-decade>) and evaluates the EU’s progress towards achieving the objectives and targets set by the Digital Decade Policy Programme (DDPP) for a successful digital transformation for people, businesses, and the environment, as set out in the decision establishing the *Digital Decade policy programme 2030* (Decision (EU) 2022/2481 of the European Parliament and of the Council of December 2022 establishing the *Digital Decade policy programme 2030*, OJ L 323, 19.12.2022, p. 4–26). It explores the key drivers and challenges to achieve the EU’s digital transformation, including a new geopolitical paradigm, fostering competitiveness in a complex economic context, entering a new age shaped by generative AI, and keeping people and societies engaged in an increasingly hybrid context.

The report takes stock of the implementation and progress towards 2030 as regards the main achievements of the EU as a global digital player and regulator, and the EU’s economic and industrial policies. It highlights the following digital transformation achievements of businesses in Europe: 64% of SMEs have a digital intensity, 52% of the enterprises have a Cloud take-up, 44% of the enterprises have a Big data take-up, 11% an AI take-up, and 53% have Unicorns (start-up companies).

The findings of the 2023 *State of the Digital Decade report* confirm that over the last five years, the EU has strategically pivoted toward a more assertive digital policy framework, recognising the urgent need to shape the digital space with targeted investments and robust regulatory mechanisms when necessary. This approach marked a significant disruption, propelling the EU to the forefront of global digital governance and policy

innovation. The European Commission’s five-year mandate of 2019-2024 has overhauled the digital policy landscape by proposing and negotiating twenty-three legislative files that have contributed to reinforcing the EU’s position in the Digital Decade (Apre, report on the state of the digital decade 2024). According to the report, the new EU-wide rules have contributed to the *Digital Decade* objectives of competitiveness, facilitated the growth of enterprises with the deepening of the single market, and shaped the digital economy far beyond its borders. Among the important legislation delivered in the last mandate is notably the *Artificial Intelligence Act* (Regulation (EU) 2024/1689), the world’s first initiative regulating specific uses of artificial intelligence based on the level of potential risk. It sought to address societal challenges, rights, and safety, including ethical considerations, while establishing effective yet light-touch requirements for AI systems operating within the EU Decade (Apre, report on the state of the digital decade 2024).

Nevertheless, the report monitors important needs in different areas: the critical need for action and investment at EU and national levels, notably Digital Skills, ICT experts, high-quality connectivity, dissemination of AI and data analytics, and start-up ecosystems. The report provides concrete recommendations to the Member States on the way forward, addressing the whole possible scope of action: mobilising investments, completing the single market, disseminating technologies, and fostering cooperation between Member States. In a nutshell, the recommendations revolve around the following main pillars:

- Implement and enforce the regulatory frameworks established to drive the digital transformation
- reduction of the administrative burden, both in the implementation and enforcement of existing legislative acts, entails promoting synergies, avoiding duplication, and adopting a coordinated approach to managing the existing governance structures, with coherence between digital and cybersecurity policy
- intensify their efforts to strengthen their competitiveness, encompassing productivity, resilience, greening, and sovereignty
- foster the dissemination of digital technologies across society and regions, particularly by developing cooperation and collaboration between European actors at the local level.
- transition from small-scale pilots and initiatives to large-scale projects based on cooperation between public and private actors

The concerns expressed in the *Digital Decade report* are confirmed by the outcomes of the European Commission workshop *AI in Agriculture* held in March 2025, where over two hundred experts convened and focused on impactful AI-based solutions for agriculture. A key objective was to identify both established and emerging AI technologies that address sector-specific needs, as well as gaps in the current market.

This workshop represented a very significant milestone, on one hand, because it was one of the first public initiatives undertaken by the new European Commission, and on the other hand, after all, AI represents a strategic topic for agriculture. Indeed, AI is already enhancing the sector’s competitiveness and environmental performance, while also reducing administrative burdens. In particular, AI applications in precision farming and decision-support systems are actively reshaping agricultural production. Moreover, AI-based solutions tend to be predominantly adopted by larger farms or bigger enterprises within the supply chain.

Participants - including industry leaders, sectoral representatives, start-ups, scientists, and policy-makers – also explored key challenges and enabling factors essential for integrating AI effectively within the agricultural sector. CEOs presented their evolving AI use cases, highlighting critical aspects such as data requirements, model scalability, and socio-economic and environmental impacts. Experts, including representatives from manufacturing, agriculture, cooperatives, and European Digital Innovation Hubs, shared insights and practical experiences on how to fully unlock the potential of AI.

Challenges identified for AI in the sector include the handling of legislation at the EU and national levels, limited capacities of end users to effectively adopt AI-based solutions, and ensuring access to sufficient data, in terms of both quality and quantity. For example, the lack of consistent data formats across EU Member States was shown to increase the costs of service providers delivering data-driven solutions. It was further

discussed that implementing an AI-based agricultural domain model could significantly reduce interface development efforts from 1,687 person-years to just 46 person-months.

Trust emerged as a pivotal factor in agricultural AI, encompassing both confidence in AI systems and readiness to share data crucial for AI development. In this context also the potential of regulation in creating conditions that foster a reliable market of safe AI applications was also highlighted.

To accelerate the development and adoption of AI-based solutions, specific actions were proposed, such as enhancing interoperability among geospatial datasets to reduce the production costs of AI-driven services, establishing a digital Farm ID, and implementing the *Common European Agricultural Data Space (CEADS)* that is aimed to pave the way for a European data space for agriculture that facilitates data sharing, processing, and analysis in a secured, trusted, transparent and responsible manner to create new opportunities for monitoring and optimising natural resource use stimulating data-driven innovations.

In conclusion, unveiling the future of digital traceability in the European food supply chain is certainly a difficult exercise. Additionally, difficulties were also noted in adequately distinguishing the EU's strategy and measures in the field of digitisation in agriculture from what is expressly provided for in the adoption of food traceability systems and technologies.

The discourse analysis of the *Strategic Dialogue* carried out through the comparison with the four priority areas outlined by the World Economic Forum, the analysis of other simultaneous (or not) EU decisions, regulations, and reports, provides the following results:

- historical background on food traceability in the EU;
- multi-stakeholder governance scheme of the impacts of digitisation in agriculture, and digital traceability systems;
- a broad consensus on the seeking of an approach, governance, and business models for the market drivers
- inventory of experiences, and best practices that identify concerns, constraints, challenges, and common essential elements to develop a coherent strategy for the EU;
- roadmap or the step-wise deployment of digital traceability, including the identification of public and private accountability that is expected to contribute to the objectives of the strategy;
- a set of recommendations for the enhancement of food traceability systems and to overcome the restraints for the diffusion/adoption of such technologies.

These elements fit into the paradigm shift that occurred in 2024 due to the changed political landscape within the European Union and the international context.

The results appear generalizable and transferable, net of the difficulties mentioned above in collecting the information. Critical discourse analysis, while powerful, faces several limitations. One key challenge is establishing a consistent methodology, as different approaches can yield varying results. Additionally, it may not fully capture the complex social dynamics underlying language use, potentially leading to an incomplete understanding. Furthermore, while discourse analysis can identify patterns, it may struggle to explain the reasons behind those patterns, leaving gaps in understanding. But it contributes to providing a context that influences the meaning of language. Ignoring the context can lead to inaccurate interpretations and misrepresentations of the data. In our case, most of the elements of the frame regarding the topic are validated through analysis and comparison and appear accurate and reliable in tracking trends and providing recommendations, contributing to the understanding of discourse on the limits and opportunities of food digital traceability systems.

6. Conclusion

The analysis of the *Strategic Dialogue* on the future of EU agriculture has allowed attention to the important and equally delicate political transition that European agriculture is undergoing, as a result of the pandemic, ongoing international conflicts and disputes, and their effects on food supply chains.

Moreover, the decision adopted by the President of the European Commission von der Leyen to launch in 2024 the *Strategic Dialogue* in the form of a close consultation among all stakeholders in the food supply chain to discuss and outline the choices to be made in the most shared manner constitutes an extraordinary element. Moreover, in a political season (2019-2024) characterized by an abundance of decisions, regulations, and initiatives from the European Union in this sector. Consider, for example, the adoption of the *European Green Deal* with the *Farm to Fork strategy*, the important decisions regarding Biodiversity, Soil, and the launch of the Common Agricultural Policy 2023-2027. Likewise, considering what has been decided over the years regarding the digital transition, the programme ‘*Europe’s Digital Decade: Digital Targets for 2030*’ aimed to transform businesses’ digital intensity and tech uptake to 75% of EU companies using Cloud, AI, or Big Data.

So, not by chance, the *Strategic Dialogue* and the broader framework that supports food traceability and digitisation in agriculture have been the focus of the analysis of the paper. The analysis was supported by a literature review that highlighted connections with other studies and the research gaps to be filled.

The analysis provided, through the critical discourse methodology and drawing from primary and secondary sources, three primary results:

- having historicized the European strategy on food traceability within a conceptual and temporal framework;
- the confirmation of the adherence of the agri-food stakeholders to digitisation in agriculture and the adoption of technologies in food traceability;
- the sharing of a series of recommendations that gather various categories of concerns and issues expressed by stakeholders, aiming for a new European roadmap characterized by greater progressiveness in goals and broader involvement of the actors of the agri-food sector, consumers included.

These results represent an original contribution to the contemporary study of food traceability in Europe.

The analysis also allows the formulation of the following recommendations to be considered as market drivers for the enhancement of food traceability systems:

-Customer Demand for Transparency: People are becoming more and more concerned about the safety and provenance of the food they eat. More openness in the food supply chain is made possible by traceability technologies, which empower customers to make more informed decisions.

-Stricter Regulatory Requirements: Stricter standards about food safety and traceability are being implemented and enforced by governments and regulatory agencies across the world. The adoption of traceability systems by food firms is significantly influenced by their compliance with regulatory requirements.

-Globalization of the Food Supply Chain: As a result of the food supply chain becoming more globalized, improved product tracking and monitoring are required when goods travel across national boundaries. Throughout the supply chain, traceability technologies aid in guaranteeing the quality and safety of food items.

-Food Fraud Concerns: Mislabeling and adulteration are two issues that the food sector must deal with. By enabling the tracking and authentication of product provenance, traceability technologies serve to lower the risk of food fraud.

-Enhancement of Supply Chain Efficiency: By offering real-time visibility into the movement of goods, traceability technologies like blockchain and RFID (Radio-Frequency Identification) can improve the efficiency of the supply chain. This may result in less waste and improved inventory control.

-Technological Developments: As a result of ongoing developments in fields like blockchain, data analytics, and the Internet of Things, more complex and trustworthy traceability solutions are being created. Companies now find it simpler to deploy traceability systems due to these technical improvements.

-Growing attention to Sustainability: The food sector is placing an increasing amount of attention on sustainability and ethical sourcing. Technologies for traceability can assist in guaranteeing that food items are sourced ethically, satisfying consumer demand for environmentally and socially conscious methods.

-Integration with Smart Packaging: Real-time product condition monitoring, including temperature and humidity, is made possible by the integration of traceability technologies with smart packaging systems. This is essential to preserving perishable foods’ safety and quality.

-Growing Awareness Among Food Producers: As the advantages of traceability become more widely known, more manufacturers and food producers are realising the importance of putting traceability solutions into place to improve their processes and satisfy consumer demands.

The recommendations include several factors that act as restraints and challenges for the food traceability technology market. These may include:

-Costs of Implementation: The upfront expenses related to putting food traceability systems into place can be high and include things like software, hardware, training, and integrating them with already existing systems. This could provide a challenge, particularly for small and medium-sized enterprises.

-Implementation Complexity: It can be difficult to integrate traceability technology into current supply chain systems, necessitating cooperation from many stakeholders. The intricacy could discourage certain companies from implementing these technologies.

-Opposition to Change: Some parties involved in the food supply chain may be reluctant to implement new traceability technology out of fear that doing so will interfere with current operations or because they are unaware of the advantages.

-Data Security and Privacy Issues: Data security and privacy issues are brought up by the food supply chain’s gathering and exchange of sensitive data. If businesses and customers don’t trust the security safeguards in place, they can be reluctant to engage in traceability systems.

-Lack of Standardisation: Interoperability problems may arise if there are no industry-wide or worldwide standards for food traceability. The efficacy of traceability projects may be impeded by the deployment of incompatible technology by various supply chain actors in the absence of standardised systems.

-Challenges in a Globalised Food Supply System: Disparities in regulations, dialects, and cultural customs might provide difficulties in an increasingly interconnected food system. Because of these differences, coordinating traceability initiatives across national borders can be challenging.

-Education and Awareness: Some stakeholders may be unaware of the advantages of food traceability technology or are unsure of how to use it successfully. Adoption processes might be slowed down by a lack of knowledge and awareness.

-Limited Resources for Small Businesses: Small-scale producers and enterprises may lack the financial and technological means to set up and keep up advanced traceability systems.

The challenges that the European system faces in ensuring food security are enormous. The paper captures some of these elements by contextualizing them within the reference period, the decisions to issue, the choices to undertake, and those to be implemented in the coming years. There are potential future research directions. The most relevant would be to examine country by country in Europe, the impact of the integration of digital tools (which technology is best to incorporate?), and the driving of food authenticity testing, to decide how to support a risk-based governance approach to improve the safety, resilience, and transparency of the

national food system. This will certainly help to support the lack of a coherent food safety approach in many countries in terms of systems and governance, especially for SMEs, who struggle to understand how compliance can be achieved.

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