EU CAP Network Focus Group

'Alternative solutions for livestock product differentiation'

Mini Paper 4

Information and Communication Technologies for product differentiation

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Summary

Technology is ubiquitous in modern European agriculture. Technological developments, such as mechanization and synthetic fertilization, supported the "Green Revolution" and the transition to a food surplus in Europe. Nowadays, technology no longer takes the form of tractors or fertilizers but rather follows the society-wide penetration of Information and Communication Technologies (ICT). Those technologies leverage the use of data to gather, store and communicate information, or use the information for applied purposes. One of the frequently claimed advantages of such technologies is that they can assist livestock product differentiation. Livestock farming has many specificities and complexities due to dealing with live animals, and therefore information-intensive technologies can assist farmers in multiple ways towards the end goal of presenting consumers with differentiated offerings. The purpose of this Mini Paper is to review how ICT enables differentiation. Here, we highlight two main avenues for livestock product differentiation through ICT: (1) **optimized on-farm production & management**, and (2) **value-chain and consumer engagement**. We present a shortlist of some examples of promising technologies briefly outlined in Figures 1 and 2.

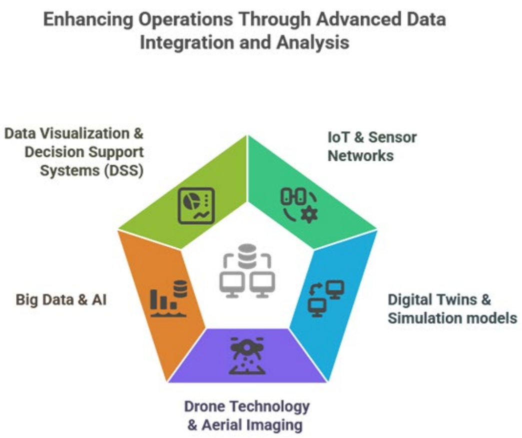

Figure 1 - Data generation and processing for operational purposes (Source: E.Krystallidou, 2025)

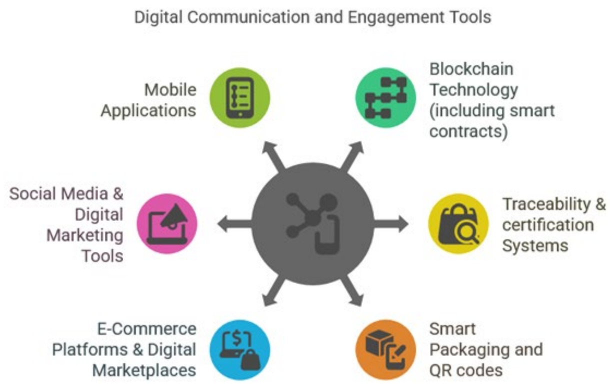

Figure 2 - Data communication and engagement tools (Source: E.Krystallidou, 2025)

Introduction

The rapid evolution of Information and Communication Technologies (ICT) has reshaped many sectors, including agrifood production. In today's competitive European market, where product differentiation is key to capturing consumer trust and securing premium pricing, leveraging ICT tools can provide a significant competitive advantage. This Mini Paper is designed to **introduce and familiarize all actors within the agrifood chain with a broad spectrum of ICT tools** that can be utilized to differentiate livestock products.

The primary purpose of the Mini Paper is thus to present an overview of diverse ICT tools and how they can help producers differentiate in the market — particularly those that support transparency, traceability, and communication. Outlining technical aspects, concrete examples, and (to the extent possible) cost–benefit analyses of ICT, this Mini Paper aims to **raise awareness among producers, processors, marketers, and policy makers about how digital solutions can contribute to product differentiation**. In essence, the goal is to offer a comprehensive toolkit that informs decision-making and encourages innovation across the agrifood value chain.

As ICT continues to see increasingly rapid rates of improvement, readers are encouraged to interpret the content as a primer on available technologies at the time of writing. The Mini Paper intends to serve as a practical guide that offers a starting point for aligning on-farm and supply chain challenges with suitable ICT interventions. The Mini Paper also serves as a call for further research, by identifying areas where additional study or tool development is needed, ultimately paving the way for more effective, sustainable, and differentiated production practices.

The Mini Paper begins by introducing some important working definitions. Then, it describes selected state-of-the-art technologies depending on their route or contribution to differentiation, addressing the pressing need to match practical challenges with available digital solutions. Finally, after drawing some conclusions about those use cases, it provides a list of research needs from practice, highlighting potential research gaps for further exploration, and ideas for Operational Groups that can be drawn from the conclusions. A detailed reference section for further information about ICT in livestock farming is provided at the end.

Definitions

Technology has been essential for the recent past of agriculture. Mechanization was critical to enable efficient labour use, while fertilization, particularly with nitrogen produced using the Haber-Bosch process, was key to enabling the green revolution and feeding a world of 7 billion people. The use of technology, however, did not come without drawbacks, one of which was the environmental pressure put on ecosystems and contributions of intensive energy use and land use change to climate change.

Recently, a notable surge of technological transformation has emerged within agrifood systems. "Information and Communication Technologies" (ICT) is a broad term that encompasses the infrastructure, tools, and services that allow for the creation, storage, retrieval, transmission, and use of information in various forms, such as text, images, sound, and video. This encompasses hardware (e.g., computers, mobile devices, sensors, and networking equipment), software (e.g., applications, operating systems, and databases), and telecommunications infrastructure (such as telephones, radio, and television) enabling individuals and organizations to communicate, access, process, and share information efficiently and effectively.

In the context of the agrifood sector, ICT refers to the use of digital technologies, ranging from the Internet and mobile applications to sensors, drones, and artificial intelligence, to support and streamline agricultural processes, improve productivity, enhance supply chain transparency, enable real-time decision making, and foster innovation. While some livestock producers have turned to traditional production approaches, others have begun using ICT tools for modernizing agricultural practices, enabling better resource management, optimizing production systems, and meeting the growing demand for differentiated, sustainable food products.

For the purpose of this Mini Paper, **ICT is defined as a suite of digital tools, systems, and services that facilitate the creation, storage, processing, transmission, and retrieval of information**. As the interest of this Mini Paper is how ICT can be leveraged to achieve product differentiation, we first defined the ways in which this link can be made. In this case, we focused on **two distinct ways that ICT can contribute to product differentiation through**:

1. **optimized on-farm production & management** (i.e. data generation and processing for operational purposes);
2. **value-chain and consumer engagement** (i.e. data communication and engagement).

Description and applicability of technologies

ICT tools vary in their cost and degree of readiness for widespread use. Each technology was thus assessed considering its potential cost of implementation and maturity level (or market readiness). This analysis is highly dependent on context - **there is a wide range of potential costs and tools with varied levels of maturity according to provider and country and therefore readers are encouraged to find specific pricing information for their farms and countries.** Therefore, the assessment of this Mini Paper should be considered indicative at the time of writing only. Costs were assessed based on an informal survey of market options across the European Union or otherwise estimated prices of equipment and services. Specific providers are not indicated in this Mini Paper as our goal was not to recommend commercial or open-source solutions. As for maturity level, the classification was mostly based on the number of providers and use cases of equipment/services that relate to the technology that can found through online search.

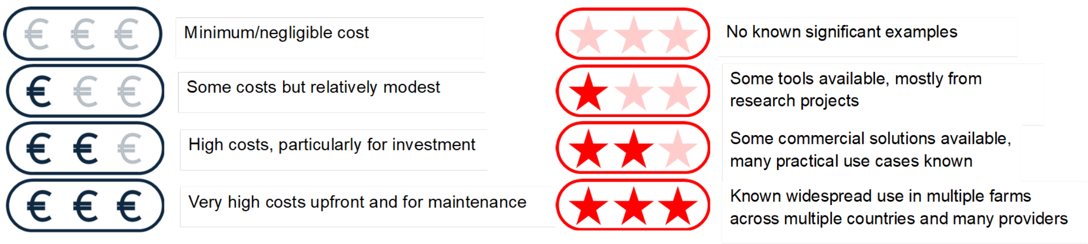

Figure 3 - Key for interpreting the cost and maturity assessment of each technology (Source: R.F.M. Teixeira, 2025)

1. Data generation and processing for operational purposes

a. Internet of Things (IoT) & Sensor Networks

IoT devices—such as wearable sensors, radio frequency identification (RFID) tags, and environmental monitors—continuously collect data on animal health, movement, and feeding behaviour. This real-time monitoring enables a high degree of precision in managing livestock. When producers can document that animals are raised under optimal conditions, they build a credible quality narrative that supports product differentiation. IoT sensors are also critical for other ICT highlighted in section 3.2, as they are used to collect source data needed for communication.

Sensors transmit data via wireless networks to centralized databases or cloud platforms. The recorded information, including feed conversion efficiency or temperature variations, is later used to verify that production practices meet premium standards. This data, when aggregated and audited, supports branding claims like "humanely reared" or "sustainably produced".

Cost assessment: €€€ (1 of 3)	By reducing manual record-keeping and enabling predictive interventions (e.g., early detection of disease), IoT systems also help maintain consistency in product quality. This consistency is a key selling point in markets where even slight quality differences command a price premium. Sensor investments typically go up to hundreds of euros. Improved herd health and reduced losses can help raise revenue margins.
Maturity assessment: ★★★ (2 of 3)	There are documented use cases by livestock farmers across Europe of IoT sensors, which have become integrated with many farm activities.

b. Digital Twins & Simulation Models

Digital twin technology creates virtual replicas of livestock production systems that simulate real-world conditions. By modelling various management scenarios, producers can optimize operations, ensuring that animals are raised under conditions that maximize product quality. This optimization can potentially directly support product differentiation by enabling consistent, high-quality output.

Technically, digital twins integrate data from sensors, weather forecasts, and historical performance, using simulation software which can be process-based models or data-driven (AI and machine learning) models. They allow for virtual "what-if" analyses that help refine feeding regimes, environmental controls, and breeding practices before changes are implemented on-farm. The resulting data-driven insights support continuous improvement in production quality.

Cost assessment: €€€ (2 of 3)	This virtual optimization not only reduces operational risks but also provides evidence that production practices meet premium standards—an important selling point in markets demanding transparency and consistency. Digital twin systems require a high upfront investment tens of thousands of euros, which can be offset through improvements in efficiency and product consistency.
Maturity assessment: ★★★ (0 of 3)	There are few examples of commercial digital twins for agricultural farms. Market penetration is low to non-existent.

c. Drone Technology & Aerial Imaging

One of the most effective ways of collecting big data for entire farms is through remote sensing paired with geographic information systems (GIS). Satellite imagery is ubiquitous, but free sources of space data such as the European Sentinel missions may have insufficient resolution for some applications. Unmanned aerial vehicles (also known as drones) equipped with high-resolution cameras and multispectral sensors (e.g. in the infrared range, thermal cameras, etc.) capture aerial images that help monitor pasture conditions, animal movements, and environmental stressors. This data supports proactive herd management by detecting issues such as overgrazing or uneven pasture quality that could affect product consistency.

Technically, drone systems integrate GPS, imaging sensors, and flight planning software to produce detailed maps and actionable insights. These aerial images can also be used for marketing purposes, offering consumers a bird's-eye view of the farm and reinforcing claims of transparency and sustainability.

Figure 4 - Aerial view of cows grazing for herd management (Source: Pexels.com)

Cost assessment:	The modest cost of drones can be offset by improved herd management and marketing benefits. However, dealing with the data collected from drones can be costly and require specialized systems and assistance.
Maturity assessment:	There are many service providers in this field and some documented use cases by livestock farmers across Europe of high-resolution aerial imaging from drones, although it cannot yet be said that this has widespread practical implementation.

d. Big Data and Artificial Intelligence (AI)

Dealing with big data is essential for many of the other ICT tools highlighted in this Mini Paper. Big data analytics uses powerful computing frameworks to process large volumes of data from sensors, production records, and market trends. AI and machine learning are algorithms that learn from big data and are capable of analyzing complex datasets from sensors, production records, and market trends to forecast animal health issues, optimize feeding regimens, and fine-tune breeding strategies. By extracting actionable insights from datasets, producers can optimize breeding, feeding, and overall herd management. Consistent, high-quality outputs that result from these optimizations can differentiate products in the market.

Technically, AI models are built using open-source frameworks and require training on historical farm data. Once deployed, these models continuously learn and adjust, providing predictive insights and recommendations that lead to improved productivity and quality. This technical precision supports the narrative of a high-tech, quality-assured production process.

Cost assessment:	The use of AI provides measurable metrics for quality control, allowing producers to demonstrate the performance of their herds. There are many free and open-source tools and algorithms online. However, development and integration costs may vary quite significantly, particularly requiring costs of computing and require experts for implementation, with the return on investment depending on the specific systems developed.
Maturity assessment:	There are service providers and online tools in this field and some documented use cases by livestock farmers across Europe of AI tools. However, automated systems are still farm from widespread practical implementation.

e. Data Visualization & Decision Support Systems (DSS)

DSS platforms aggregate and visualize data from various sources—including IoT sensors, production logs, and market trends—to support informed decision-making. These systems transform complex datasets into intuitive dashboards, enabling producers to monitor and improve herd performance. Consistent quality, verified through data, forms the backbone of a differentiated product offering.

Technically, DSS tools use software that integrates with cloud data and analytics platforms, offering interactive visualizations that highlight trends and anomalies. This clarity helps farm managers quickly pinpoint issues and adjust practices to maintain premium standards. In turn, these improvements support claims of consistent, high-quality production that can be marketed effectively. The ability to visually present performance data also enhances transparency when communicating with buyers, thereby reinforcing the product's differentiated status.

Cost assessment: € € €	Low subscription or software costs (often free or a few hundred euros annually) lead to improved operational decisions and marketing options.
Maturity assessment: ★★★	There are many DSS available online, some quite specialized in livestock production. There is ample evidence of DSS use by farmers.

2. Data communication and engagement

a. Blockchain Technology (including Smart Contracts)

Blockchain is a decentralized, secure digital ledger that records transactions immutably (Fig. 5). In livestock, it tracks data from breeding to processing, enabling full traceability from farm to fork. This transparency helps meet growing consumer demands for quality, ethics, and sustainability. Using consensus protocols and smart contracts, blockchain automates tasks like payments and quality checks, ensuring conditions (e.g., animal welfare) are met before funds are released. This reduces errors and fraud, strengthens trust, and provides a verifiable "digital passport" for products—an edge in competitive markets.

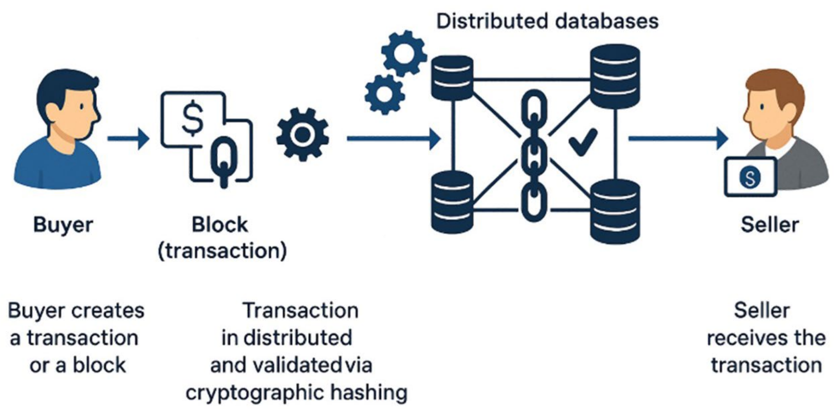

Figure 5 - Schematic depiction of blockchain-mediated transactions (Source: R.F.M. Teixeira, 2025)

Cost assessment: € € €	The initial integration is technically complex and setting up the entire infrastructure cost several thousand euros. This makes those systems very costly. On the flipside, improved traceability can reduce recall risks, combined with reduced administrative overhead.
Maturity assessment: ★★★	There are few examples of commercial blockchain applications for livestock products and are mostly attached to research projects. Turnkey commercial solutions are scarce. Market penetration is low to non-existent.

b. Traceability & Certification Systems

Traceability systems record every step of livestock production using technologies such as RFID, barcode scanning, and blockchain. These systems generate a detailed "digital passport" for each product, verifying that the production methods (including animal welfare and sustainable practices) meet high-quality standards. Such verifiable information is crucial for differentiation in European markets.

Technically, these systems integrate with supply chain management software and can operate in real time. They provide an auditable trail that not only reduces the risk of fraud but also reassures consumers that the product meets stringent certification criteria. Certification—whether for organic, animal welfare, or regional authenticity—enhances the product's market value.

Cost assessment:	By assuring quality through rigorous documentation, traceability systems enable producers to command a premium price and build stronger brand loyalty. Initial costs are upwards of a few thousand euros, but products with verifiable quality can potentially earn a price premium, and improved traceability reduces risks of costly recalls.
Maturity assessment:	There is evidence of many support systems for traceability and certification and many practical use cases and adoption by livestock producers.

c. Smart Packaging & QR Codes

Smart packaging integrates digital codes (QR codes, near field communication (NFC) tags) on product packaging, enabling consumers to access detailed information about production practices, animal welfare, and sustainability with a simple scan. This instant transparency supports a premium brand image by verifying that the product meets high-quality standards.

Technically, smart packaging solutions use inexpensive printing and tagging technologies. When a consumer scans the QR code, they are directed to an online database containing the product's "digital passport," including traceability records and certification details. This immediate access to information builds trust and reinforces the product's unique qualities. The system also supports post-sale engagement by allowing consumers to provide feedback and share their experiences online. In markets like Europe, where consumers are increasingly discerning about food origins and production practices, this level of transparency is a powerful differentiator.

Cost assessment: € € €	Smart packaging generally incurs minimal cost (often just a few cents per unit).
Maturity assessment: ★★★	Although this technology has been proposed many years ago and there is definitive evidence of producers using it for communication, there is little evidence of widespread use by most brands.

d. E-Commerce Platforms & Digital Marketplaces

E-commerce platforms allow producers to sell their differentiated livestock products directly to consumers, bypassing traditional intermediaries. This direct channel emphasizes product origin, quality, and ethical production practices, thus reinforcing a premium brand image. The digital storefront becomes an integral part of the differentiation strategy by allowing detailed storytelling and transparency.

Technically, these platforms integrate secure payment systems, inventory management, and customer analytics. They can be optimized for both desktop and mobile, ensuring that consumers have a seamless buying experience. Integration with traceability systems further strengthens the product's narrative by providing instant access to production data.

Cost assessment: € € €	In markets such as Europe, where consumers in certain niche markets value local, authentic, and traceable products, e-commerce can boost margins by reducing transaction costs and eliminating intermediaries, which can offset commissions paid to the platforms (typically 5–15%).
Maturity assessment: ★★★	Although many such markets are available, there is little evidence of widespread use by farmers, who mostly seem to continue preferring conventional commercialization channels.

e. Social Media & Digital Marketing Tools

Social media and digital tools help producers craft authentic brand stories. By sharing behind-the-scenes content, certifications, and ethical practices, farmers build trust and stand out through transparency—especially in European markets that value sustainability. Partnering with influencers expands reach and boosts credibility. Instagram or YouTube collaborations can spotlight farming practices and promote products to wider audiences.

Digital marketplaces like Facebook Business and LinkedIn offer precise targeting and analytics, allowing tailored messaging around quality and ethics. Social media's interactive nature also enables real-time feedback, helping producers adapt and engage effectively.

Cost assessment:	Very low costs spent on social media websites (often free or modest monthly fees) can lead to increased consumer engagement.
Maturity assessment:	Although not fully widespread, there is a vast pool of farmers and brands that now communicate through social media directly with consumers.

f. Mobile Applications

Mobile apps deliver real-time farm management, advisory, and market information directly to farmers' smartphones. As more than 80% of European farmers own smartphones, this is a particularly interesting and low-cost method for collecting and delivering data. These applications enable producers to monitor livestock, receive health alerts, and obtain up-to-date price information, all of which support consistent product quality.

From a technical standpoint, mobile apps are built on cross-platform frameworks and integrate with cloud systems and IoT data streams. They offer user-friendly interfaces, push notifications, and interactive dashboards that help farmers adjust practices immediately. The enhanced decision-making process translates into improved animal welfare and product consistency.

Cost assessment:	Mobile platforms facilitate direct communication between producers and consumers, reinforcing transparency and traceability. Many mobile apps are free or cost under €10 per month, and the only hardware needed is often the smartphone itself to record the data.
Maturity assessment:	The widespread use of smartphones by farmers (over 80% in the European Union) makes the use of apps very common, with a plethora of apps and mobile systems available and practically used by farmers.

Existing best practices and tools

This section provides specific examples of projects (a), labels (b) and digital marketplaces (c) and other similar initiatives for connecting producers and consumers that use some of the technologies described in the previous chapter. The lists of projects, labels and marketplaces should be understood as exemplifying of how ICT for livestock production is used by such initiatives.

a. Research projects and Operational Groups

This section contains a list of projects and OGs that either developed tech or used tech included in the list in Section 3.

- **MIWA - SMART REUSABLE PACKAGING** H2020 Project (1/1/2022-29/2/2024)
  MIWA creates a complex and highly scalable ecosystem of Smart Reusable Packaging, built as an integrated hardware and software solution, with embedded IoT elements, connected to a vast digital environment and powered by advanced data analytics. The Miwa Project developed a smart cup as part of its innovative approach to reducing packaging waste and promoting sustainable consumption. This smart cup is embedded with RFID technology, enabling it to be easily tracked and reused within a closed-loop system. Designed for use in bulk dispensing machines, the cup allows consumers to purchase products without single-use packaging, aligning with zero-waste goals. Its integration with a digital platform also supports user engagement by tracking consumption patterns and encouraging environmentally responsible behavior.
- **ColorSensing Tracking true colors** H2020 Project (1/11/2018-31/3/2019)
  The ColorSensing project developed an innovative, non-invasive food freshness indicator aimed at reducing food waste and enhancing consumer confidence. By utilizing smart inks that change color in response to the conditions inside food packaging, this technology provides real-time information about product freshness. Consumers can easily assess the quality of packaged foods, leading to more informed purchasing decisions and potentially reducing unnecessary disposal of still-edible products. Additionally, the integration of this indicator with digital solutions enables monitoring of freshness throughout the supply chain, ensuring transparency and safety from production to consumption.
- **CLEARFARM**: Co-designed Welfare Monitoring Platform for Pig and Dairy Cattle H2020 Project (1/10/2019-31/3/2024)
  The ClearFarm project has developed a digital platform that utilizes precision livestock farming (PLF) technologies to monitor and enhance animal welfare in pig and dairy cattle production. By integrating data from various sensors, the platform provides real-time insights into animal health and behavior. For consumers, this translates into greater transparency regarding the welfare standards of animal-derived products. By scanning a QR code on product packaging, consumers can access detailed information about the animal's

welfare throughout its lifecycle, enabling more informed purchasing decisions. This initiative not only empowers consumers but also promotes sustainable and ethical livestock farming practices.

> **Blockchain.pt — Decentralize Portugal with Blockchain Agenda**, funded by the Portuguese Recovery and Resilience Program, The Portuguese Republic and The European Union (EU) under the framework of Next Generation EU Program (1/1/2023 – 31/12/2025)
  Project Blockchain.pt aims to decentralize Portugal, both technologically and geographically, promoting equitable and sustainable development, using a new national blockchain pipeline as an innovation engine. Work package 1 is developing "farm-to-fork" traceability tools for the agri-food sector with the development of specialized IoT solutions and their integration with blockchain systems. This work includes cheese and beef production in the region of Fundão. Massive use of sensors at farms, including GPS trackers for animals, transformation and distribution is used to collect data autonomously. Those data are then the basis for a mobile app that is under development for consumers.

b. Specific labels and certification schemes

Table 1 indicates some examples of labels and certification schemes and illustrates how ICT can be/is used within their framework to assist farmers. More information of certification can be found in Mini Paper 2.

Table 1 – Description of labels and certification schemes and how they can be assisted by Information and Communication Technologies (ICT)

Name	Products	Description	ICT connection
Global Animal Partnership	Beef cattle, pork, chicken, dairy cattle, sheep, goats, farmed salmon and bison.	A multi-tier animal welfare certification program that monitors space, feed, and behavior	IoT and Precision Livestock Technologies enable continuous animal welfare data collection and verification
Red Tractor	Poultry, dairy, beef and lamb and pork	A comprehensive food assurance scheme covering traceability, animal health and welfare, product hygiene	IoT sensors and PLF technologies aid in monitoring animal conditions and product traceability

Name	Products	Description	ICT connection
		and production sustainability	
Certified Humane	Poultry, dairy and beef cattle, sheep, goats, turkeys, bison, deer, water buffalo, farmed salmon and pork	Ensures high welfare standards with strict requirements for living conditions and care and applications in processing facilities for egg grading and packing, meat processing and slaughter facilities	IoT solutions and PLF technologies can be used for monitoring space, temperature, nutrition and behavioral aspects in real-time
Rainforest Alliance (For Sustainable Livestock)	Dairy and beef cattle	Promotes sustainable farming practices and biodiversity preservation	IoT-enabled monitoring of land use and deforestation risks ensures sustainable sourcing and production
Beter Leven	Poultry, dairy and beef cattle, veal calves, pork, turkeys, rabbits	A welfare-focused certification that awards products based on adherence to strict animal care criteria behind the product.	IoT and PLF technologies can enhance compliance monitoring with real-time welfare tracking
Friend of the Earth	Meat and dairy	Focuses on animal welfare, low environmental impact, and sustainable farming methods	IoT and PLF technologies help track environmental metrics and animal conditions to ensure compliance
Label Rouge	Poultry, beef, lamb, calves and pork	Ensures premium quality and traditional farming methods	IoT can verify production practices and traceability through advanced monitoring and record-keeping
Soil Association	Organic meat, pork and poultry	Organic certification with additional animal welfare and environmental standards	IoT and PLF technologies assist in tracking and managing pasture rotations, feeding schedules, and overall health metrics

c. Markets connecting supply chain actors

Table 2 shows some examples of markets that link producers and consumers with information and communication technologies (ICT) and illustrates how this linkage can be achieved.

Table 2 – Examples of markets connecting producers and consumers with Information and Communication Technologies (ICT)

Name	Overview	IoT/PLF Integration	Consumer Connection
Provenance Chain Network	Provenance is a platform that uses blockchain and IoT technologies to trace the journey of animal products through the supply chain. By capturing data at each stage, from farm to retailer, it ensures product authenticity and quality	Integrates IoT devices to monitor conditions such as temperature and humidity during transportation and storage, ensuring product quality	Enables consumers to access detailed information about the product's origin, handling, and environmental impact by scanning a QR code
Big Barn	A farm-to-consumer marketplace that connects local producers with consumers, focusing on traceable and high-welfare meat and dairy products	Encourages producers to use technology for traceability and animal welfare reporting	Provides transparency by offering farm-level information and product history through digital product profiles
Farmdrop	A digital marketplace that connects local farmers directly with consumers, offering fresh meat, dairy, and eggs	Allows producers to share real-time data on animal welfare and production conditions through IoT sensors and blockchain	Consumers can view product traceability, including information on animal welfare and environmental practices, before purchasing
LocalFoodNodes	A community-driven platform connecting consumers with local	Farmers use IoT technology to monitor and	Consumers can view detailed production

Name	Overview	IoT/PLF Integration	Consumer Connection
	farmers, including meat and dairy producers	report on farm operations and share data-driven insights	practices and make informed purchasing decisions directly from the platform

Conclusions

The goal of this Mini Paper was to give a brief overview of ICT tools, for the purpose of introducing them to producers and decision-makers. We showed that:

(a) ICT enables product differentiation by supporting transparent data collection on farms and enhancing communication across the supply chain, especially with consumers. However, a clear cost-benefit analysis of ICT tools remains challenging—costs vary by region and provider, while revenue impacts are often unquantified or undisclosed. As a result, the business case for adoption is still uncertain.

(b) The level of maturity of ICT tools remains generally low. Most tools do not yet have suppliers across all countries in Europe, or there is lack of evidence of widespread adoption by farmers, which can mean that they are not yet market-ready. Nevertheless, there are examples of commercial solutions for almost all technologies surveyed, meaning that farmers with capacity for investment could potentially use all of them today.

(c) Most mature ICT tools are typically low cost, while higher cost technologies are often less mature. This observation can be explained by the fact that market-ready technologies are designed for broad adoption, whereas less mature tools remain niche. It is important to make ICT tools available to a wide range of producers, or otherwise only a few will be able to benefit from their potential.

(d) ICT is becoming increasingly important for labelling. Technologies such as **blockchain** can assist reliability and traceability within labelling schemes and provide a link between farm-level processes and claims of quality, region of origin or environmental performance. However, there are few application cases probably due to the costs involved at the time of writing.

(e) ICT tools are deeply interconnected. In some cases (a) there is a direct stream of information shared (data moved from one to another), in others (b) they share hardware/software, and in others (c) they are conceptually linked. For example:

- **IoT** is essential because online sensors are the basis for many of the other ICT tools to work. They collect the primary data that can be transformed and relayed to consumers.
- **DSS** are final users of data generated elsewhere and critical to defining and implementing improvement strategies that can later on be communicated using DSS results. They are an important intermediary between on-farm ICT and ICT for communication.
- **Mobile applications** are also essential as communication devices, both as receptors of data for farmers to better manage farms, and as enablers of digital markets and digital marketing.

Research needs from practice

Research needs from practice that arise from the assessment of the current maturity of technologies are the following:

- ***Technology development for cost reduction of ICT tools*** - Most ICT tools that can lead to product differentiation require high costs for producers. The costs are mostly of two types: (a) high capital/investment costs for equipment, (b) high consulting or subscription costs particularly for software. The high costs involved, even if the potential increase in revenue proves to be real, may be a deterrent for most livestock producers in Europe. There is a need to continue researching ways, and developing associated technologies, that use the same working principles but are produced for the mass market. For hardware/equipment, this requires simplifying and producing technology that is cheaper. For software, this requires the development of open-source systems that can be used by non-experts. Otherwise, ICT use will remain a premium service for larger producers.
- ***Removing barriers to adoption of ICT tools*** - Besides cost, there are other important barriers to adoption. An important one is the fact that the potential benefits in terms of revenue from products that use ICT are still, for the most part (as shown in section 3), speculative, without duly quantified business cases that are publicly and transparently reported. While the link of technologies with differentiation is clear, it is much less clear what is the payback time of investments because it is difficult to find information for past practical and real cases. Therefore, more research must be done on the link between ICT, farmer adoption and consumers rewarding differentiated products.
- ***Combining technologies in usable aggregated and simplified ICT tools*** - Most ICT tools must be used in combination for effective product differentiation.

For example, IoT enables data collection, which can be processed by DSS and verified through blockchain. Such tool clusters can enhance performance, traceability, and reduce costs. However, integration remains a challenge—many tools, like mobile apps, still rely on manual input rather than automated IoT or DSS data. Establishing these connections is essential for broader adoption and efficiency.

- ***Enhancing data accuracy and reliability* of ICT**- ICT effectiveness depends on accurate, high-quality, often real-time data. Yet, current systems face issues like frequent sensor calibration, inconsistent inputs, and monitoring challenges. Addressing these requires clear best-practice guidelines for standardized data collection and the deployment of more robust, durable sensors across the supply chain—key steps toward reliable farm-level analytics.
- ***Upgrading ICT usability and farmer training*** - As many farmers struggle with the technical expertise required to effectively implement ICT solutions, leading to underutilization, the development of user-friendly interfaces and apps, may simplify use for them. In conjunction with educational initiatives and well-structured extension services, knowledge-sharing will be encouraged, leading to a highly productive user experience.

Ideas for research and Operational Groups

We propose the following concepts for research projects or Operational Groups:

- Innovation projects or Operational Groups for developing open source, turnkey and low-cost solutions for producers to improve and communicate better results (environmental or for product quality). Such projects require taking the basic technologies and working on developing new hardware and software based on co-creation with farmer input.
- Operational Groups for deploying ICT tools based on IoT to farmers with high-value (quality or sustainability) production systems to relay information to consumers reliably. This includes work with consumer associations to estimate acceptance of the information and valorisation of product characteristics depicted and quantify tangible results in terms of revenue for producers.
- Innovation projects to integrate ICT approaches into reduced cost bundles, estimating their cost and doing trials to quantify adoption, potential market penetration and cost-benefit analysis for producers.

Highlight: example detailed idea for Operational Group

Title: Digital tools for differentiation

Problem tackled: There is a lack of ways for farmers to demonstrate product quality/production system sustainability in ways seen as reliable and valuable to consumers. There is a general lack of trust in claims of e.g. sustainability (green washing), and a disconnect between consumers and producers that makes it difficult for buyers to valorise high natural or human (e.g. health) value embedded in products

Concept idea: Establishment of a digital data-driven protocol that demonstrates the differentiated features of products – for example, a digital twin of a farm that showcases high biodiversity value in a visual digital world

Potential necessary activities: Development of a digital infrastructure, identification of the value added/characteristics to showcase in the system, implementation and testing, dissemination of results

Actors involved: Farmers with already established digital infrastructure; agronomists and farmer advisors for assisting with implementation; IT experts for developing digital infrastructure; retailers for showcasing the systems to consumers

Implementation: Potentially in any European region with extensive livestock production

References

This section includes further readings for who wants to know more. We recommend as a first step the consultation of websites with more information (e.g. magazine articles) on each technology listed in the following section "a". For readers who want to understand the technologies and go more in-depth into each one, we also provide suggested scientific papers in section "b". All projects, labels and marketplaces mentioned in the text above are also listed afterwards in the following sections.

a. Articles and websites on ICT and livestock systems

- "A snapshot of digital tools for livestock development", https://livestockdata.org/member-spotlight/snapshot-digital-tools-livestock-development, accessed 14/02/2025
- "Impact of information communication technology in livestock production and health management", https://justagriculture.in/files/magazine/2021/october/012%20Impact%20of%20information.pdf,
- "New Technologies Set to Transform Farming Practices in 2025", https://freshtrack.com/new-technologies-set-to-transform-farming-practices-in-2025,
- "Smart Farming: Technologies & Benefits For Agriculture", https://eos.com/blog/smart-farming/,

- "The Future of Farming: utilizing Data Analytics in Agriculture", https://iabac.org/blog/the-future-of-farming-utilizing-data-analytics-in-agriculture,
- "Livestock Tech: Innovations in Animal Farming", https://thefarminginsider.com/livestock-animal-farming-tech/,
- "A snapshot of digital tools for livestock development", https://livestockdata.org/member-spotlight/snapshot-digital-tools-livestock-development,
- "Big Data and Agriculture: A Complete Guide", https://www.talend.com/resources/big-data-agriculture/,
- "Precision livestock farming: Tools and technologies for efficiency", https://agrimachinery.africa/livestock/precision-livestock-farming-tools-and-technologies-for-efficiency/,
- "Sharing is caring: The importance of data-driven management in livestock food production", https://www.allflex.global/blog/livestock-monitoring-data-sharing/,

b. Scientific papers and books

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c. Research projects and Operational Groups

- MIWA - SMART REUSABLE PACKAGING (https://doi.org/10.3030/190134541)
- ColorSensing Tracking true colors (https://doi.org/10.3030/101113831)
- CLEARFARM: Co-designed Welfare Monitoring Platform for Pig and Dairy Cattle (https://doi.org/10.3030/862919)
- Blockchain.pt (https://blockchain.pt/)

d. Specific labels and certification schemes

- *Global Animal Partnership* (GAP, https://globalanimalpartnership.org/)
- *Red Tractor* (https://redtractor.org.uk/)
- *Certified Humane* (Humane Farm Animal Care, https://certifiedhumane.org/)
- *Rainforest Alliance* (For Sustainable Livestock, https://www.rainforest-alliance.org/in-the-field/our-journey-to-more-sustainable-cattle-ranching/)
- *Beter Leven* (https://beterleven.dierenbescherming.nl/)
- *Friend of the Earth* (Sustainable Livestock Farming,https://friendoftheearth.org/live-sustainably-2/sustainable-farming/)
- *Label Rouge* (https://www.inao.gouv.fr/Les-signes-officiels-de-la-qualite-et-de-l-origine-SIQO/Label-Rouge)
- *Soil Association* (https://www.soilassociation.org/)

e. Markets connecting supply chain actors

- *Provenance Chain Network* (https://www.theprovenancechain.com/)
- *Big Barn* (https://www.bigbarn.co.uk/)
- *Farmdrop* (https://farmdrop.us/)
- *LocalFoodNodes (https://www.localfoodnodes.org/en)*