



D2.1 Relevant products & applications of digital technologies for livestock tracking, identified gaps & barriers and recommendations for bridging the gaps

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Abstract:	One of the overarching goals of Digi4Live is to gain a better understanding of the potential of data-based tracking solutions and digital technologies in the livestock sector and the effects that regulatory, technical and commercial operating environments have on the use of these technologies. Deliverable 2.1 is a crucial step towards reaching the above goals. The objective of Deliverable 2.1 was two-fold: (i) to create an inventory of existing datasets, data collection technologies and systems and assess the information content in terms of quality and usability and (ii) to identify data gaps, barriers to interoperability, and the potential for linking and repurposing existing data or initiatives through workshops and studies. An inventory of livestock tracking industry products, applications, datasets, and projects was created following systematic online research. Moreover, key informant interviews (n=52) with various stakeholders (software developers, technology providers, farmers, industry stakeholders, public authorities and research institutes) from nine countries, relevant to the projects' six case studies, were performed to assess their features (user requirements, maturity, planning and implementation strategy, needs for standardization, conformance and certification, data sharing and legislation, associated costs, and data strategy). A systematic literature review and a webinar with stakeholders were performed to identify the major gaps and barriers in the adoption of livestock tracking technologies. In total 378 industry products, applications, datasets and projects related to livestock tracking were identified and included in the Digi4Live inventory. The majority was used for dairy cows and the most frequent application area was animal health and welfare. Results from the key informant interviews with stakeholders, suggested that most of livestock tracking tools and datasets were highly useful and relatively easy to use, had a high maturity level, complied with regulatory standards and had undergone efficient conformity assessment. The major identified standardization needs were related to compatibility, compliance, and security. The biggest initial setup and ongoing costs were for software development, maintenance, support and training. Stakeholders' attitude towards data sharing was positive and the added value

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	of data usage was recognized. Data collection automation and integration, financial incentives and building trust among parties were considered imperative to increase data sharing and usage in the future. Several gaps and barriers in the use of livestock digital technologies were identified related to standardization, interoperability, technical skills, data privacy, security, robustness and quality. To effectively bridge the gaps related to costs, technical skills, data robustness and quality, targeted actions by specific actors are essential, such as improving technical skills and further collaboration between farmers, farm advisors, and sensor producers. Gaps in standardization, interoperability, privacy and security require a collaborative approach that involves a range of stakeholders. Trust was also associated with several themes, indicating that initiatives for building trust (e.g. training, communication and demonstration) are imperative for a wider uptake of digital technologies.
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Table 1: List of abbreviations and acronyms.

List of Abbreviations and Acronyms	
AI	Artificial intelligence
ATP	Agricultural technology provider
CS	Case study
DPP	Digital product passport
EBV	Estimated breeding value
EU	European Union
GDPR	General Data Protection Regulation
GHG	Greenhouse gas emissions
GPS	Global positioning system
IoT	Internet of things
IPPC	International Plant Protection Convention (IPPC)
LCA	Life cycle assessment
LCI	Life Cycle Inventory
PEF	Product Environmental Footprint
PLF	Precision livestock farming
RFID	Radio frequency identification
TRACES	Trade Control and Expert System
WOAH	World Organization for Animal Health
WP	Work package

1. Introduction

Digi4Live aims to **enhance the capacity** of the livestock sector actors across Europe to harness data-generating and digital technologies effectively. By adopting a multi-actor (co-creation) approach (Franco Ferreira et al., 2019), the project engages stakeholders across the livestock value chain, from farm to fork, including technology suppliers, competent authorities, intermediates, retailers and R&D initiatives. Through co-creation of digital and data solutions, Digi4Live fosters greater adoption of technologies and data for livestock tracking and tracing.

One of the **overarching goals** of Digi4Live is to gain a better understanding of the potential of data-based tracking solutions and digital technologies in the livestock sector and the effects that regulatory, technical and commercial operating environments have on the use of these technologies. Specifically, within the framework of WP2, Digi4Live aims to (i) synthesize existing policies, regulations, R&I & industrial initiatives, datasets and technologies for the integration of data and data generating systems and conclude their potential and caveats and (ii) identify technologies on the market, as well as gaps, barrier, and enabling factors (regulatory, social, economic, technical) related to their exploitation.

Deliverable 2.1 represents a crucial step towards reaching the above goals. The objective of Deliverable 2.1 was two-fold: (i) to create an inventory of existing datasets, data collection technologies and systems and assess the information content in terms of quality and usability and (ii) to identify data gaps, barriers to interoperability, and the potential for linking and repurposing existing data or initiatives through workshops and studies. Specifically, the present deliverable includes the following:

- A report on industrial and research solutions: A structured report and database of relevant products, and applications of digital technologies for livestock tracking (led by AUA). This report is organized in two parts: (i) the inventory of livestock tracking datasets and tools, and (ii) the key informant interviews to assess their features (user requirements, maturity, planning and implementation strategy, needs for standardization, conformance and certification, data sharing and legislation, associated costs, and data strategy).
- A report on gaps and barriers, their root causes and drivers together with recommendations for bridging the gaps (led by Luje).

2. Products and applications of digital technologies for livestock tracking

2.1. Inventory of livestock tracking datasets and tools

2.1.1. Objective

The objective was to create an inventory of existing datasets, data collection technologies, and systems for livestock tracking and assess their information content.

2.1.2. Methodology

2.1.2.1. *Identification of industry products, applications, datasets, projects and initiatives*

A systematic online search for livestock tracking tools, datasets, projects and initiatives was performed. Identification criteria were defined that included three categories, namely main category (industry products, applications, datasets, projects, and initiatives), application area (animal health/welfare, production,

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resilience, transparency and traceability, animal tracking, reproduction and breeding, feed intake and grazing, environment, policy and administration), and animal species - production system (dairy cows, dairy sheep/goats, beef cattle, meat sheep, pigs, and poultry). Further keywords that assisted the online search per type of tool/dataset included the following:

- 1) Industry products: Internet of Things (IoT), sensors, precision livestock farming (PLF), global positioning system (GPS), smart management system, robotic milking, digital livestock farming.
- 2) Industry applications: Application, app, web app, microchip, radio frequency identification (RFID) smart reader, smart farming, biodiversity, environment, greenhouse gas emissions (GHG).
- 3) Datasets: GPS, antibiotics, product quality, genetic analysis, proficiency test, breeders' organizations, identification, milk meters, sensors, robots, digital technologies, drones.
- 4) Projects: sustainability, innovative practices, farm management, farming systems, climate change, GHG emissions, food security, product quality, novel tools, feed efficiency, genomic selection, economics, carbon footprint, breeding, cost-benefit, impacts, technologies.

A google sheet was created as a basis for developing the inventory of livestock tracking datasets and tools and partners were asked to input relevant information from the online search. Briefly, it included five different sheets, one for each of the main categories (industry products, applications, datasets, projects, and initiatives). In all cases, the following information was included:

- 1) General registration information (registration date, name and email of partner organization who registers the information, product/application/dataset/project/initiative).
- 2) Name of product/application/dataset/project/initiative.
- 3) Company/owner information (name, country, website, access rights for datasets, and funding instrument, duration, and coordination for projects).
- 4) Short description.
- 5) Application area.
- 6) Animal species.
- 7) End user.
- 8) List of relevant keywords.
- 9) Any other comments.

Screening and evaluation of input information was performed. Specifically, duplicates of tools and datasets were identified and excluded from the google sheet. Moreover, the website for each tool/dataset was visited and the validity of relevant information included in the google sheet was assessed and when necessary revised.

2.1.2.2. Inventory database design

The Inventory platform was engineered to be a scalable and efficient system that leverages cutting-edge web technologies to dynamically manage and display inventory data. Its frontend architecture was developed using Next.js and TypeScript, providing a robust foundation for Server-Side Rendering (SSR), Static Site Generation (SSG), and dynamic client-side interactivity. By adopting modular React components, the platform ensures high levels of reusability, maintainability, and scalability.

Currently hosted on Vercel, the platform benefits from seamless serverless deployment, rapid static generation, and efficient global content delivery (CDN). At this stage, inventory data was hardcoded directly into the frontend application as a static data integration approach, ensuring optimal performance without compromising functionality or data presentation. As the platform is expected to be hosted in another environment, at the official website of the Digi4Live project, its architecture remains adaptable to integrate

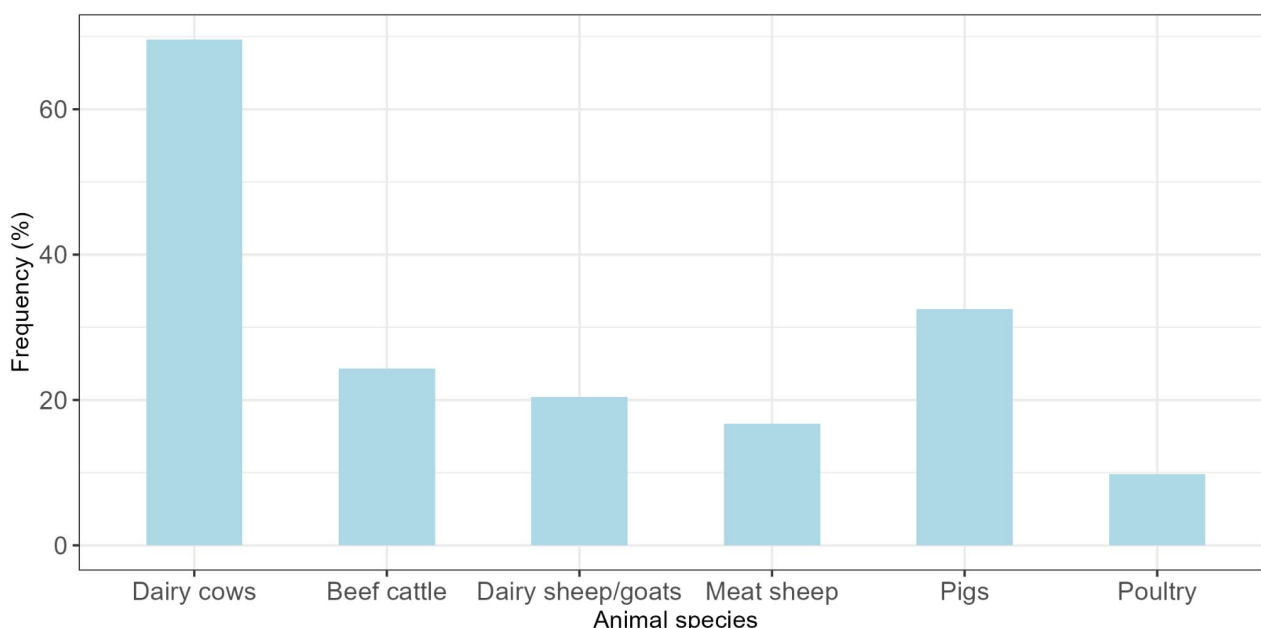
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with dynamic backends and databases, ensuring continued scalability, flexibility, and compatibility with new infrastructure requirements.

2.1.3. Results

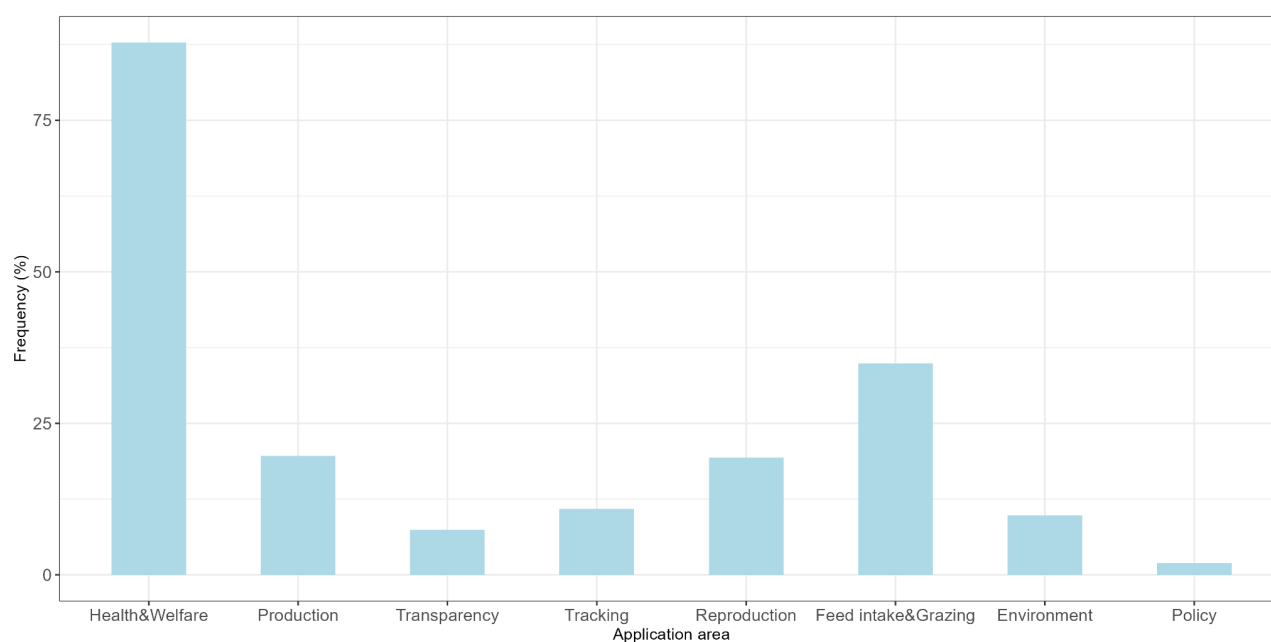
2.1.3.1. Products and applications of digital technologies per animal type and application area

A total of 306, 15, 20, and 37 industry products, applications, datasets and projects were identified; no other relevant initiatives were reported that were not included in any of the above main categories. Total frequencies per animal species and application area are presented in Graphs 1 and 2, respectively. The respective frequencies at the main category level are presented in Tables 2 and 3. The majority of identified datasets and tools (69.6%) were used for dairy cows, followed by pigs (32.5%), beef cattle (24.3%), dairy sheep and goats (20.4%), meat sheep (16.7%), and poultry (9.8%; Graph 1). In terms of application area, the majority of digital solutions were used for monitoring animal health and welfare (87.8%); feed intake and grazing, production, reproduction and breeding, animal tracking, environment, resilience, transparency and traceability, and policy-administration features were reported in 34.9%, 19.6%, 19.3%, 10.9%, 9.8%, 7.4%, and 1.9% of cases, respectively (Graph 2). Environment, resilience transparency and traceability, production, and policy-administration application areas were mostly reported (56.8%, 56.8%, 35.1%, and 13.5%, respectively) in livestock tracking projects.



Graph 1: Frequency (%) of identified livestock tracking tools and datasets (all main categories) per farm animal type.

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Graph 2: Frequency (%) of identified livestock tracking tools and datasets (all main categories) per application area.

Table 2: Number (N) and frequency (%) of identified industry products, applications, datasets, and projects per fam animal type.

Animal Species - Production system	Products		Applications		Datasets		Projects	
	N	%	N	%	N	%	N	%
Dairy cows	223	72.9	9	60.0	10	50.0	21	56.8
Beef cattle	64	20.9	4	26.7	6	30.0	18	48.6
Dairy sheep/goats	45	14.7	4	26.7	8	40.0	20	54.1
Meat sheep	38	12.4	1	6.7	6	30.0	18	48.6
Pigs	94	30.7	6	40.0	3	15.0	20	54.1
Poultry	14	4.6	4	26.7	7	35.0	22	59.5

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Table 3: Number (N) and frequency (%) of identified industry products, applications, datasets, and projects per application area.

Application area	Products		Applications		Datasets		Projects	
	N	%	N	%	N	%	N	%
Health & welfare	283	92.5	10	66.7	9	45.0	30	81.1
Production	51	16.7	5	33.3	5	25.0	13	35.1
Resilience, transparency & traceability	2	0.7	2	13.3	3	15.0	21	56.8
Animal tracking	32	10.5	1	6.7	6	30.0	2	5.41
Reproduction & breeding	59	19.3	3	20.0	4	20.0	7	18.9
Feed intake & grazing	121	39.5	4	26.7	4	20.0	3	8.10
Environment	12	3.9	2	13.3	2	10.0	21	56.8
Policy & administration	0	0	0	0	2	10.0	5	13.5

2.1.3.2. Database of digital technologies – Inventory Digital Platform

The inventory was hosted on the digital platform created by Agricultural University of Athens, that can be temporarily accessed through the following link: <https://aqa-site.vercel.app/> (Figure 1). This inventory includes all the information collected by partners for digital solutions in livestock tracking after quality control and evaluation. The following features are available for easy access and navigation:

- “Search” engine: Allows for easy search and access to information related to specific digital solutions in livestock tracking (Figure 1).
- “Browse Solutions” tab: Allows for easy navigation through the different main categories, namely industry products, industry applications, datasets, project, and initiatives per animal species and application area (as described above, Figure 2).

By selecting a specific product, application, dataset or project users can access all relevant information including website, company, application area, animal species, end users, relevant keywords, organization that registered it and registration date (Figure 3).

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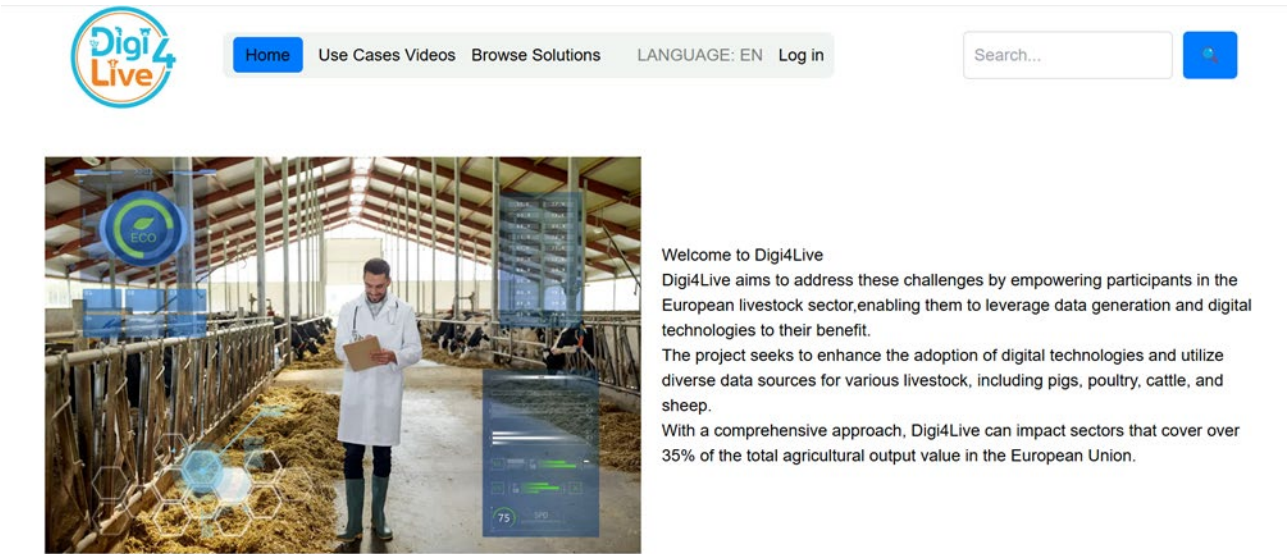


Figure 1: Website of Digi4Live inventory of livestock tracking datasets and tools.

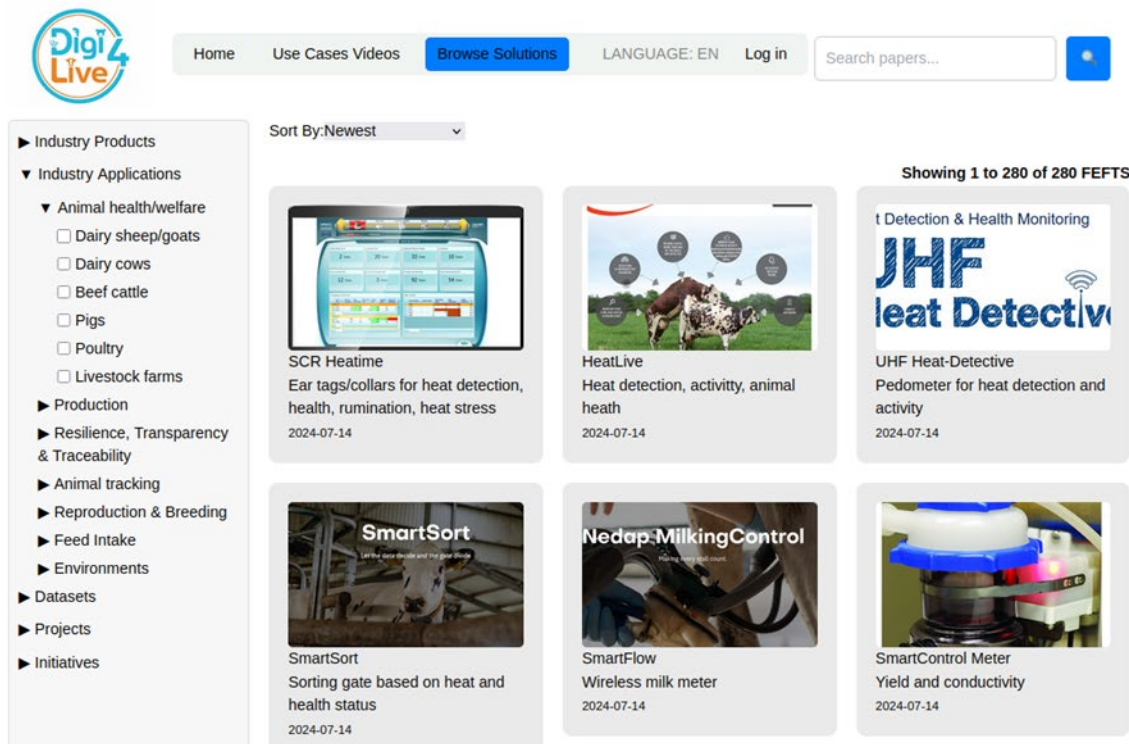


Figure 2: Navigation through main categories of digital solutions per animal species-production system and application area.

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SmartBox Master.

Information	
WEBSITE OF COMPANY Access website here	COMPANY NAME/COUNTRY FarmControl/Portugal
APPLICATION AREA Animal health/welfare and Industry Products	USED FOR Poultry/Pigs
END USER OF THE PRODUCTS Farmers	LIST OF RELEVANT KEYWORDS IoT, Sensor data, edge computing, equipment management
ORGANIZATION OF USER WHO REGISTERS THE PRODUCT Agricatural University of Athens	REGISTRATION DATE 2024-03-20

Figure 3: Information provided for each livestock tracking product, application, dataset, project, and initiative.

2.2. Key informant interviews on gaps, barriers and features of livestock tracking datasets and tools

2.2.1. Objective

The objective was to systematically collect information and obtain in-depth knowledge on livestock tracking datasets and tools and R&I initiatives (user requirements, maturity, planning and implementation strategy, needs for standardization, conformance and certification) through interviews with relevant stakeholders.

2.2.2. Methodology

2.2.2.1. Structured questionnaire and interview protocol

A structured questionnaire to systematically collect information on livestock tracking datasets, tools and services was created by AUA and finalized with the inputs of all involved partners. The questionnaire (Annex 1) was organized into seven main sections namely (i) general, (ii) user requirements, (iii) maturity, planning and implementation strategy, (iv) needs for standardization, (v) conformance and certification, (vi) data sharing and legislation, (vii) associated costs, and (viii) data and strategy. Briefly, each of the sections included questions aiming to assess the following:

- **General:** Type of product, company, country, application area, and animal species.
- **User requirements:** Purpose of use, data input needs, devices/platforms and technology/equipment, internet connection and signal availability, help documentation, type of payment model and license. Moreover, questions regarding perceived usefulness and ease of use were included and rated on level of agreement using a 7-point scale (from 1 = “Strongly disagree” to 7 = “Strongly agree”, with 4 = “Neither agree nor disagree”).
- **Maturity, planning and implementation strategy:** Level of automation, updates, supported languages, equipment integration capabilities, data export and storage, and customization options.
- **Needs for standardization:** Functionality and reliability, compatibility, security, compliance and support were rated in terms of standardization needs using a 5-point scale (1 = “Low” to “5” = High).
- **Conformance and certification:** Conformance with national and international regulatory standards, activities involved in conformity assessment, and authorization party.
- **Data sharing and legislation:** Strategy towards data sharing, familiarity with the new EU legislation, additional costs and benefits related to the legislation.
- **Associated costs:** Major initial setup and ongoing operational costs.
- **Data and strategy:** Importance of data usage and perceived added value.

An interview protocol was created and discussed with involved partners through online meetings. The first step was to create a list of potential stakeholders to be interviewed taking into account their relevance and experience with digital technologies, the identified solutions included in the inventory (described above), and the six case studies (CS) of the Digi4Live project. Then, partners contacted these stakeholders to describe the aims of the project and specifically of WP2 interviews and assess their availability and interest to participate; an example of written communication with stakeholders is presented in Annex 2. Following a positive response, an interview was scheduled and performed either in person or through an online call. Finally, a report was prepared summarizing the main findings from the interviews at case study level.

2.2.2.2. Interviews – Links with the inventory and the case studies

In total 52 semi-structured, key informant interviews were conducted. Their general characteristics are presented in Table 3. Interviews were organized by partners AUA, LUKE, INRAE, IDELE, WU, WR, Thünen, IGBZ, KUL and DTI. Interviewed stakeholders included representatives from Greece (n=14), France (n=10), the Netherlands (n=8), Poland (n=6), Denmark (n=4), Finland (n=4), Germany (n=3), Belgium (n=2), and

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Austria (n=1; Table 4). Overall, interviewed stakeholders can be classified as software developers, technology providers or users; the latter included livestock farmers and farmer organizations, farmer consultants, industry stakeholders (e.g. breeding companies, dairy companies, slaughterhouses retailers), public authorities and research institutes. They were generally selected based on their relevance with the identified livestock tracking datasets and tools of the inventory and the aims of the six CSs of the project. Specifically, 9, 10, 7, 6, 14, and 6 interviews were related to CS-A, CS-B, CS-C, CS-D, CS-E and CS-F, respectively.

CSs have been presented in Deliverable 3.1. Briefly, CS-A focuses on developing harmonized datasets for pig and broiler production chains, integrating livestock health and welfare data to increase welfare and health levels in the production chain. CS-B aims to enhance the resilience and transparency of livestock supply chains through the integration and effective use of diverse data types in the TRACES (Trade Control and Expert System) platform. CS-C aims to develop an artificial intelligence (AI)-driven adaptive tracking system for pigs and dairy cow production chains, with the core objective of enhancing the robustness of AI models to ensure stable performance under diverse environmental conditions. CS-D focuses on examining the use of digital technologies for boosting animal breeding. CS-E aims to organize and facilitate farm-level data collection in intensive pig and poultry farming systems and increase the speed in conducting LCA studies for such systems, via the development of digital LCA tools. CS-F focuses on developing dataspace proof-of-concept which will apply to e.g., policy monitoring, environmental certification and food traceability (through the development of digital product passport (DPP) to increase transparency, accountability, and traceability for each actor in the value chain.

CS-E (Data digitization for environmental impact assessments using LCA) cannot be directly associated with the assessment of livestock tracking tools, datasets and services. Thus, to establish a link with CS-E, it was considered necessary to further employ several questions during this interview process, about LCA as a method to estimate the environmental performance of livestock products.

These questions targeted to assess: (i) the familiarity of the respondents with the LCA and the EU Product Environmental Footprint (PEF) method; (ii) the relevance of the development of web-based data import templates and Life Cycle Inventory (LCI) software for the respondents' organization; (iii) the key challenges for primary data collection and LCA in livestock farming according to the respondents; (iv) the specific features and functionalities in web-based data import templates, according to the respondents, for their user-friendliness and effectiveness in farm-level data collection; (v) the data formats or standards the respondents currently use or prefer for LCA; (vi) the primary data the respondents could share for developing the tools of CS-E; (vii) the respondents' interest in participating in the development and testing phases of these tools; (viii) the ways that the respondents would be willing to promote and support the adoption of these tools within the industry once they are developed; (ix) the benefits the respondents anticipate from using these tools in their operations and (x) the incentives and support the respondents would need to adopt and integrate these tools into their business practices.

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Table 4: General characteristics and number (N) of interviews per case study, country, and partner.

Case study	Interviewed organization type	Country	Partner	N	Total
A	Software providers, farmers, farmer organizations, retailers, public authorities & research institutes	Germany	WU	3	9
		The Netherlands	WU & Thünen	6	
B	Software developers, public authorities, farmer organizations, animal transportation companies	Poland	IGBZ	6	10
		Denmark	DTI	4	
C	Software providers, farmer organizations	France	IDELE	4	7
		Belgium	KULEUVEN	1	
		The Netherlands	KULEUVEN	2	
D	Software providers, research institutes, farmer organizations, breeding companies	France	INRAE	6	6
E	Software developers, technology providers, consultants, farmers	Greece	AUA	14	14
F	Software producers, breeding companies, public authorities, data intermediation services	Finland	LUKE	4	6
		Belgium	LUKE	1	
		Austria	LUKE	1	
TOTAL					52

2.2.2.3. Data analysis

Descriptive statistics of standardized qualitative data from all interviews were performed using the R statistical package “summarytools” (Comtois, 2022) and visualized with R package “ggplot2” (Wickham, 2016). Moreover, the main findings from each case study and interview section (user requirements, maturity, planning and implementation strategy, needs for standardization, conformance and certification, data sharing and legislation, associated costs, data and strategy) were summarized by involved partners.

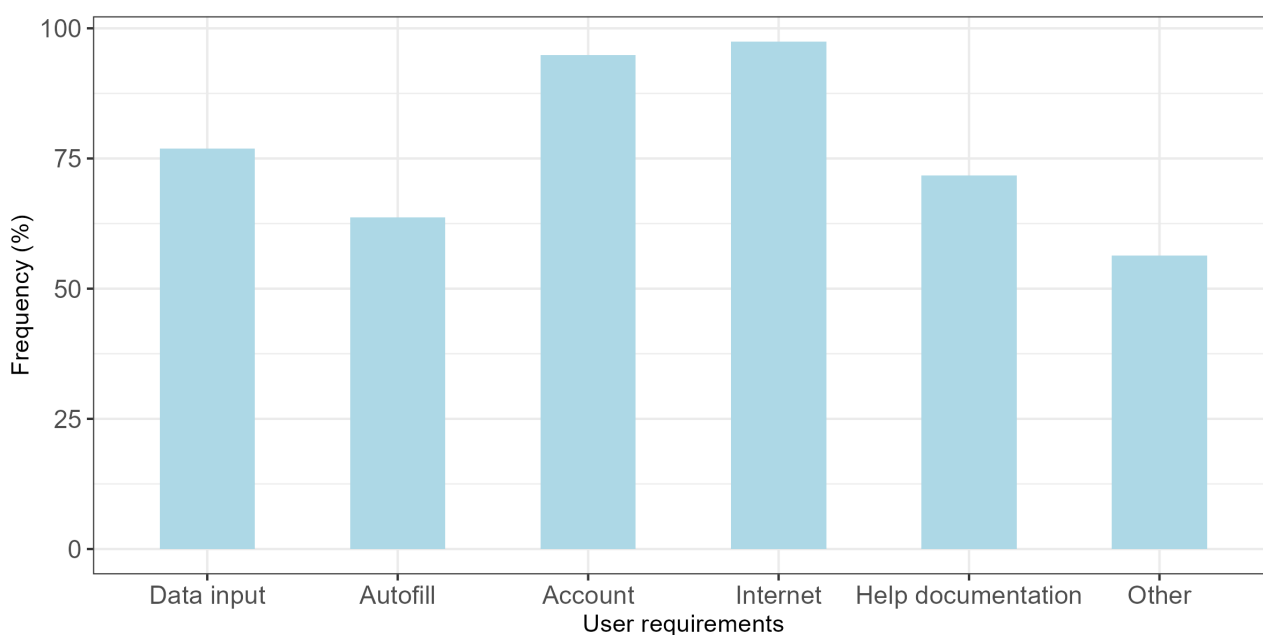
2.2.3. Results

2.2.3.1. Assessment of livestock tracking tools and datasets

2.2.3.1.1. User requirements

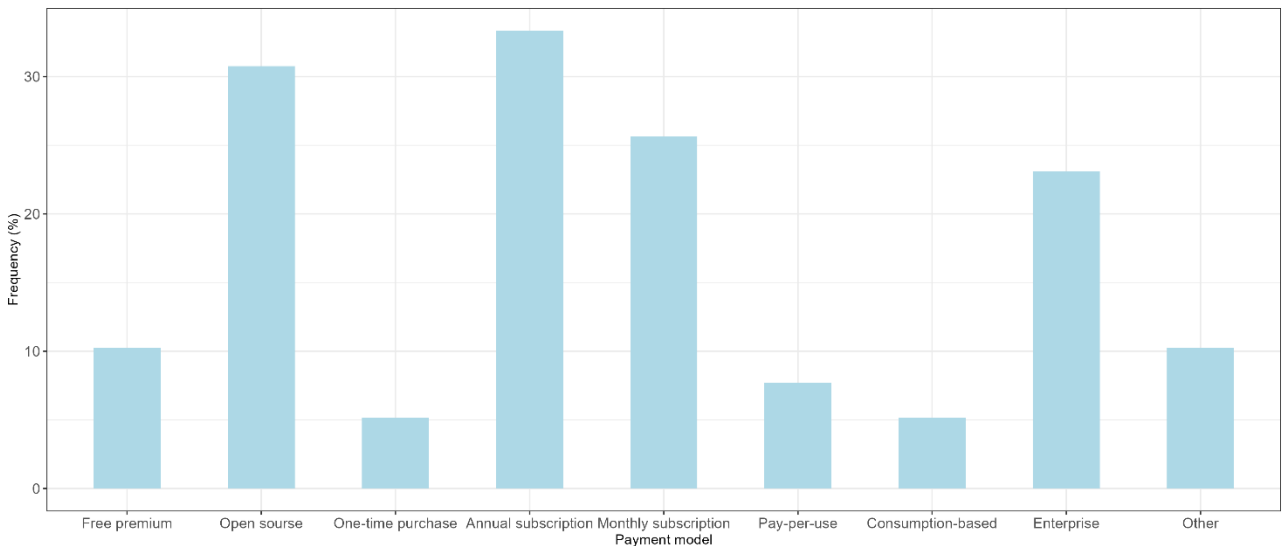
Frequencies of identified user requirements, payment and license models of livestock tracking tools and datasets reported by the interviewed stakeholders are presented in Graphs 3, 4 and 5, respectively. In the majority of tools and datasets (76.9%), data input was required, however in most cases (63.6%) they could be automatically filled to reduce time and amount of data entry. Users needed to create an account and have internet access to use most of the studied digital solutions (94.8% and 97.4%, respectively). Help documentation was also reported to be largely needed (71.8%) and hence, it was provided in the majority of cases (94.8%). Approximately half of the respondents (56.4%) reported that additional materials or information (mainly through training and consulting) were needed to use the tool or database (Graph 3). The most frequent payment models were annual subscription (33.3%) and open source (30.8%), followed by monthly subscription (25.6%), enterprise pricing (23.1%), free premium (10.3%), pay-per-use (7.7%), and consumption-based (5.1%); other types of payment models were also reported such as trial-periods (10.3%; Graph 4). The most frequent license was the proprietary (66.7%); freeware (30.8%), shareware (5.1%), open source (2.6%), and freemium (2.6%) licenses were also reported (Graph 5).

Perceived usefulness and ease of use are reported in Table 5. Most of the respondents extremely or quite agreed that the tools/databases helped to accomplish tasks more quickly (87.2%), improved job performance (61.5%), increased productivity (71.8%), enhanced effectiveness (71.8%), and were overall useful (89.7%). Likewise, they extremely or quite agreed that they were clear and understandable (61.5%), easy to become useful at (66.7%), and easy to use (59.0%).

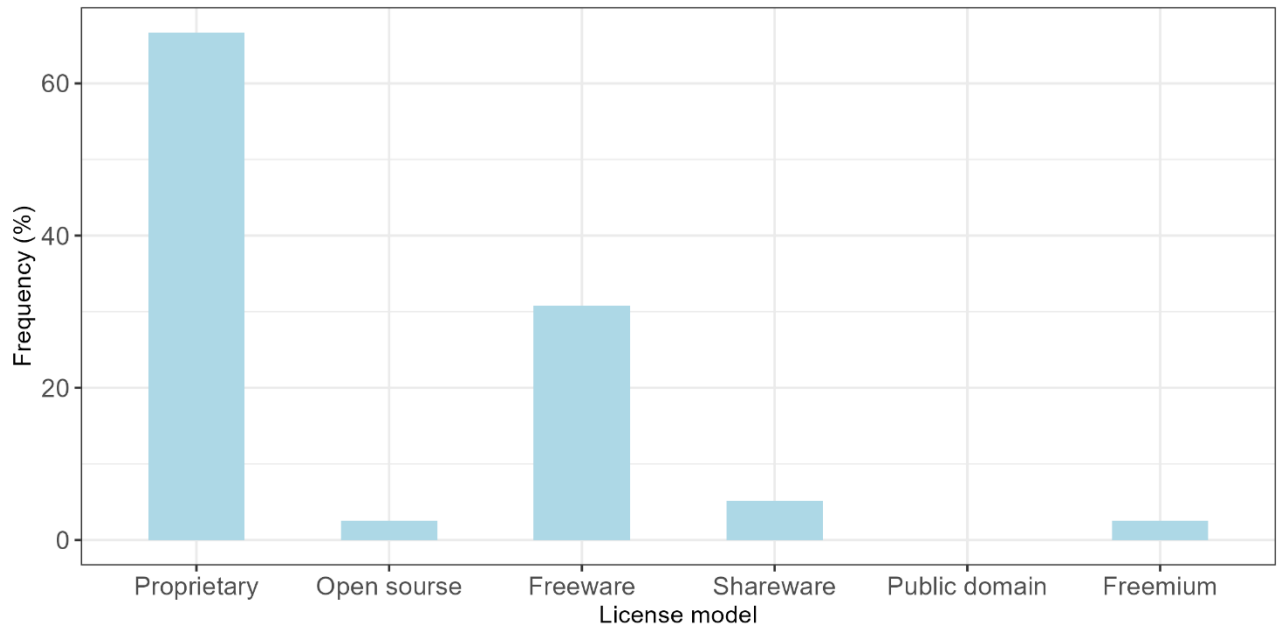


Graph 3: Frequency (%) of user requirements for livestock tracking tools/datasets reported by the interviewed stakeholders.

D2.1 Relevant products & applications of digital technologies for livestock tracking, identified gaps & barriers and recommendations for bridging the gaps



Graph 4: Frequency (%) of payment models for livestock tracking tools/datasets reported by the interviewed stakeholders.



Graph 5: Frequency (%) of license models for livestock tracking tools/datasets reported by the interviewed stakeholders.

D2.1 Relevant products & applications of digital technologies for livestock tracking, identified gaps & barriers and recommendations for bridging the gaps

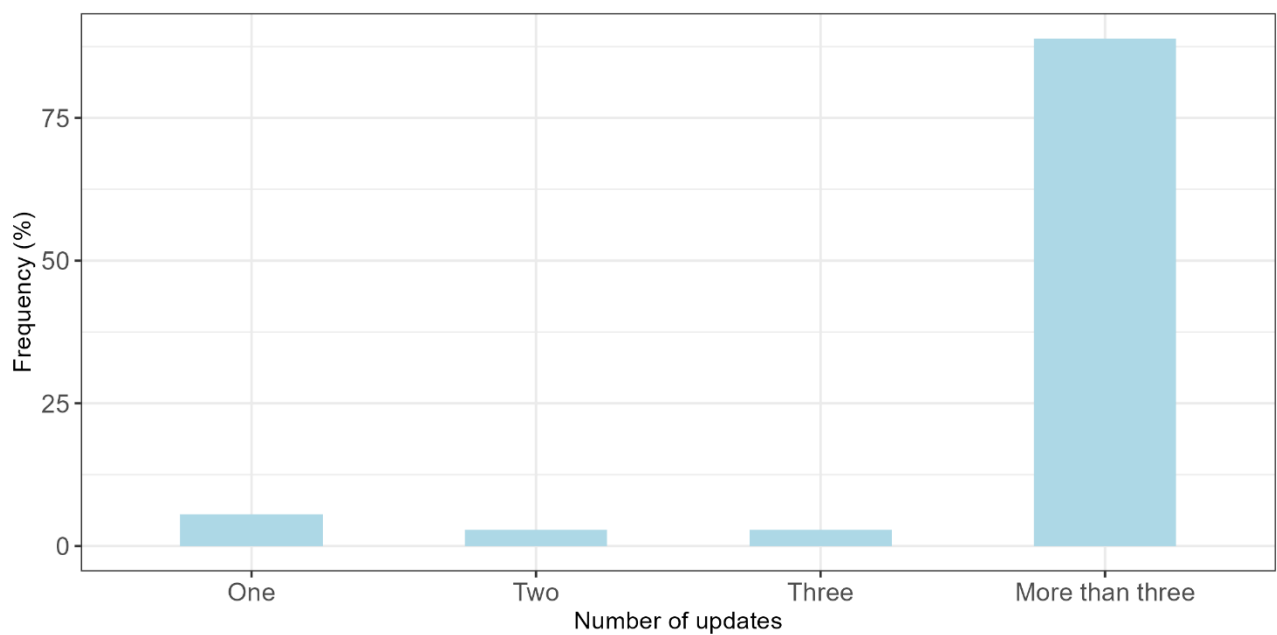
Table 5: Frequency (%) of interviewed stakeholders' agreement (1=extremely disagree, 2=quite disagree, 3=slightly disagree, 4=neither agree nor disagree, 5=slightly agree, 6=quite agree, 7=extremely agree) with statements regarding perceived usefulness and ease of use of livestock tracking datasets/tools.

Perceived usefulness & ease of use	Level of agreement						
	1	2	3	4	5	6	7
Accomplishing tasks more quickly	0	0	0	5.1	7.7	35.9	51.3
Improving job performance	0	2.6	2.6	5.1	28.2	30.8	30.8
Increasing productivity	2.6	0	0	5.1	20.5	33.3	38.5
Enhancing effectiveness	0	0	0	5.1	23.1	30.8	41.0
Useful	0	0	2.6	0	7.7	30.8	59.0
Easy to learn	0	0	2.6	12.8	25.6	33.3	25.6
Clear & understandable	0	0	5.1	5.1	28.2	35.9	25.6
Easy to become skillful at	0	0	7.7	2.6	23.1	43.6	23.1
Easy to use	0	0	5.1	12.8	23.1	33.3	25.6

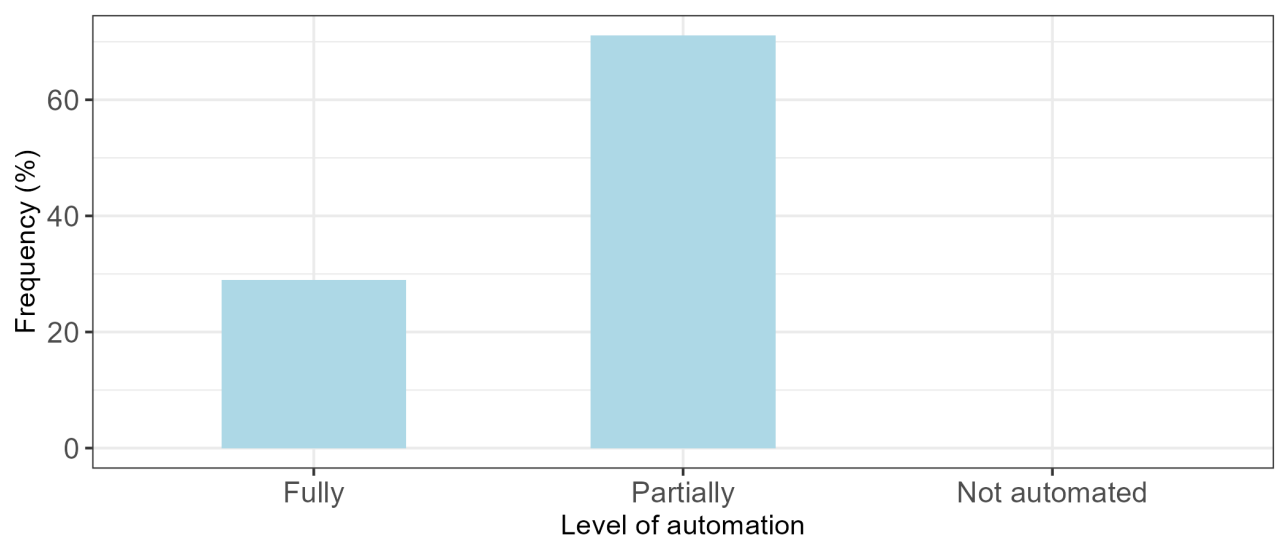
2.2.3.1.2. Maturity, planning and implementation strategy

Elements of maturity and future plans reported by the interviewed stakeholders are presented in Graphs 6, 7, 8, and 9. The majority of tools/datasets had been updated more than three times (88.9%; Graph 6), and they were partially automated (71.1%; Graph 7). Multiple languages, equipment integration, data export, data storage and customization options were supported in most of the studied cases (79%, 89.2%, 91.9%, 94.7%, and 78.4%, respectively; Graph 8). The most frequently reported future plans included further updates (85.7%), automation (77.1%), and inclusion of more languages (61.1%). Amongst the organizations that did not support equipment integration, data export, storage and customization options, 50.0%, 33.3%, 0.0%, and 78.4%, reported them in their future implementation strategy (Graph 9). Other plans (29.0%) reported by the stakeholders included optimization of data import, real-time data, android applications, and interoperability.

D2.1 Relevant products & applications of digital technologies for livestock tracking, identified gaps & barriers and recommendations for bridging the gaps

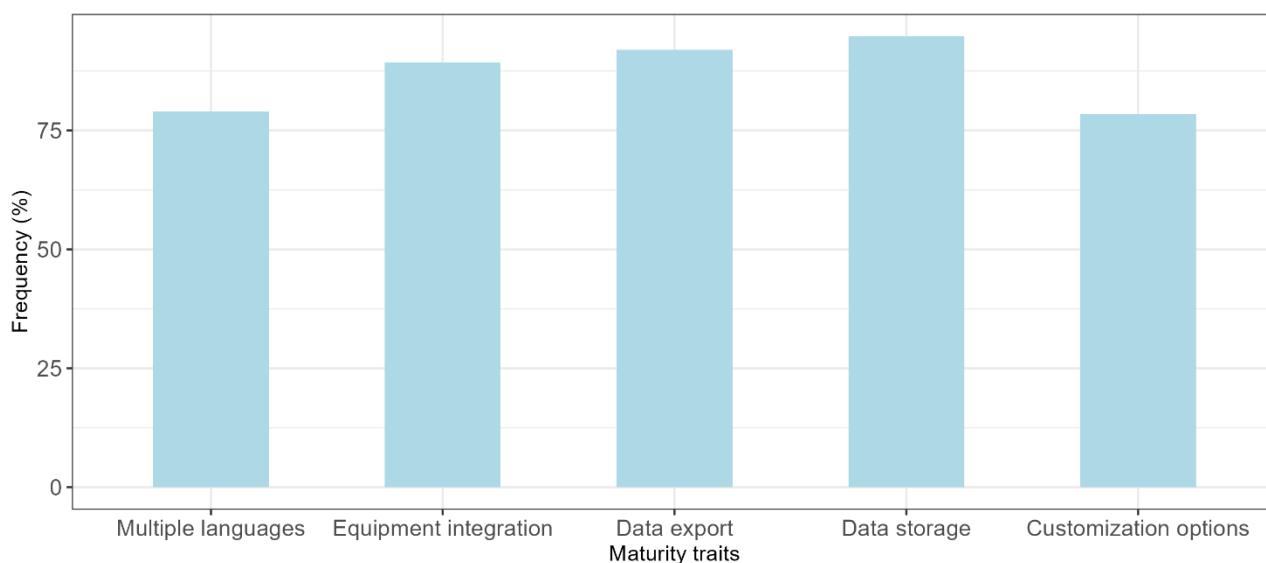


Graph 6: Frequency (%) of number of updates for livestock tracking tools/datasets reported by the interviewed stakeholders.

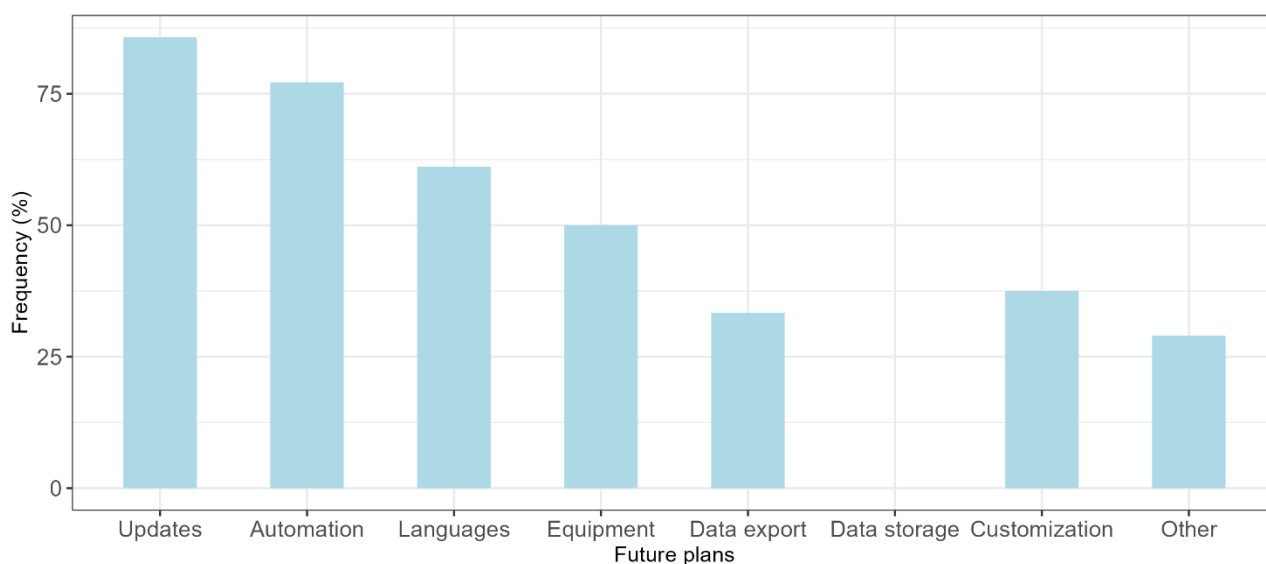


Graph 7: Frequency (%) of automation levels for livestock tracking tools/datasets reported by the interviewed stakeholders.

D2.1 Relevant products & applications of digital technologies for livestock tracking, identified gaps & barriers and recommendations for bridging the gaps



Graph 8: Frequency (%) of other maturity traits related to livestock tracking tools/datasets reported by the interviewed stakeholders.



Graph 9: Frequency (%) of future plans related to livestock tracking tools/datasets reported by the interviewed stakeholders.

2.2.3.1.3. Needs for standardization

Standardization needs according to the interviewed stakeholders are presented in Table 6. The most frequently reported aspect in a high need for standardization was compatibility (39.4%), followed by security and compliance (26.3% in both cases), functionality/reliability and support (21.1% in both cases). Overall, high or slightly high standardization needs were reported for compatibility, compliance, security, functionality/reliability and support by 63.2%, 55.3%, 50.0%, 47.4%, and 42.1% of stakeholders, respectively.

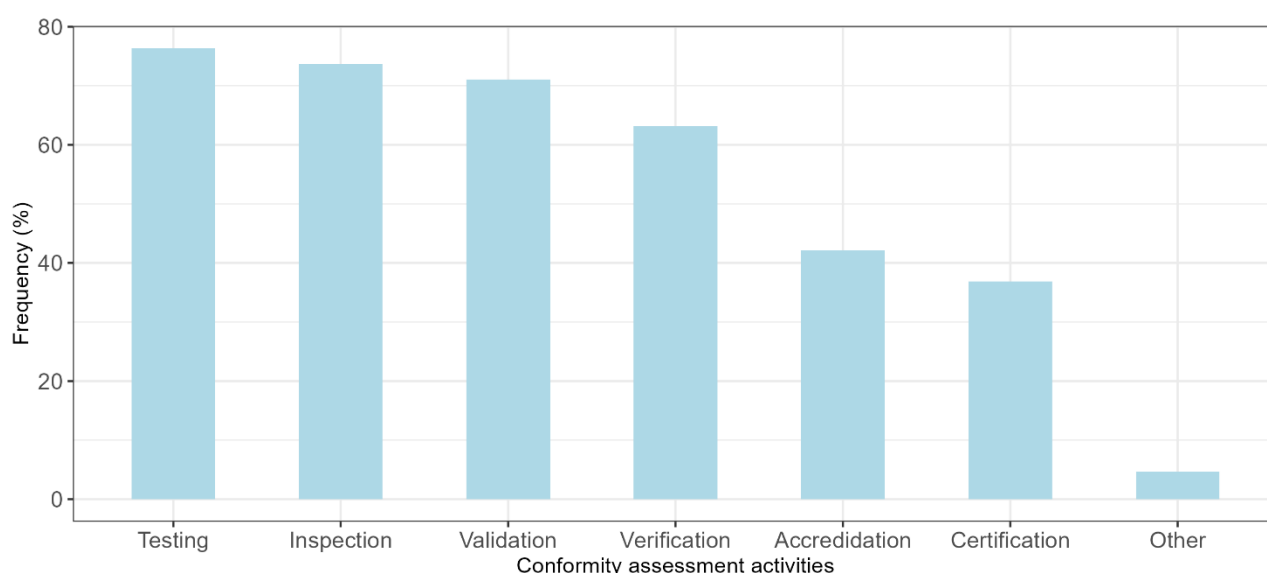
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Table 6: Frequency (%) of standardization needs (1=low, 2=slightly low, 3=medium, 4=slightly high, 5=high) per studied aspect reported by the interviewed stakeholders.

Standardization needs	Level of need				
	1	2	3	4	5
Functionality & Reliability	18.4	26.3	7.9	26.3	21.1
Compatibility	18.4	7.9	10.5	23.7	39.5
Security	29.0	13.2	7.9	23.7	26.3
Compliance	29.0	13.2	2.6	29.0	26.3
Support	26.3	15.8	15.8	21.1	21.1

2.2.3.1.4. Conformance and certification

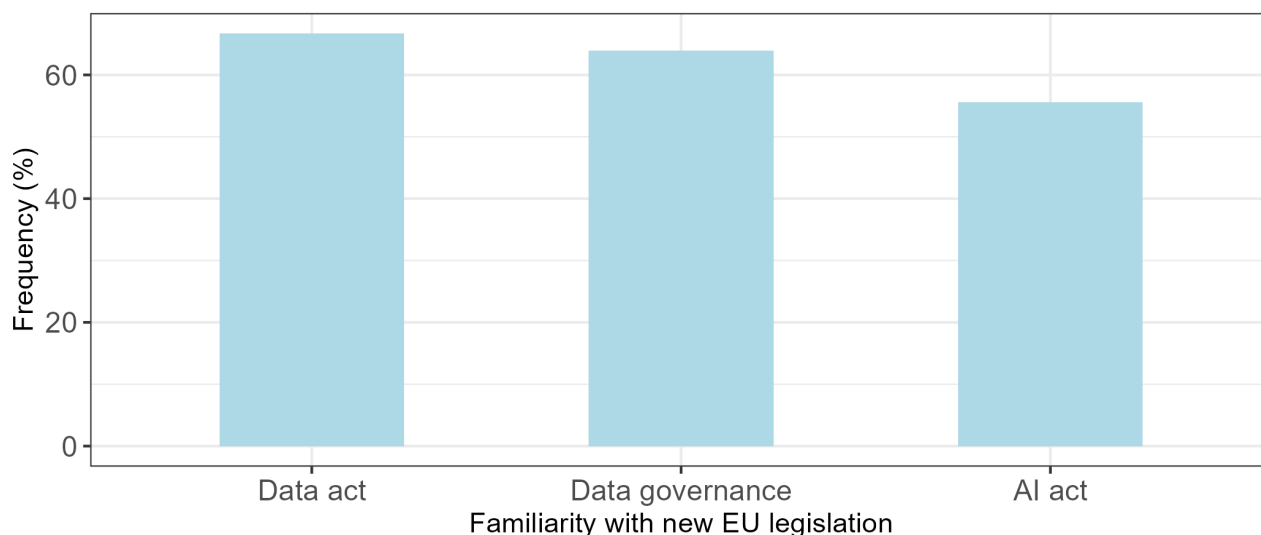
The majority of studied tools and datasets (86.5%) complied with national and international regulatory standards (such as CE mark). The activities involved in conformity assessment are presented in Graph 10. Specifically, in most cases, testing, inspection, validation and verification were performed (76.3%, 73.7%, 71.1%, and 63.2%, respectively); accreditation and certification were less frequently reported (42.1% and 36.8%, respectively). Relevant certifications were in most cases provided by a test laboratory (56.7%) or the manufacturer (40.0%); in some cases (3.3%) other authorization parties were reported.



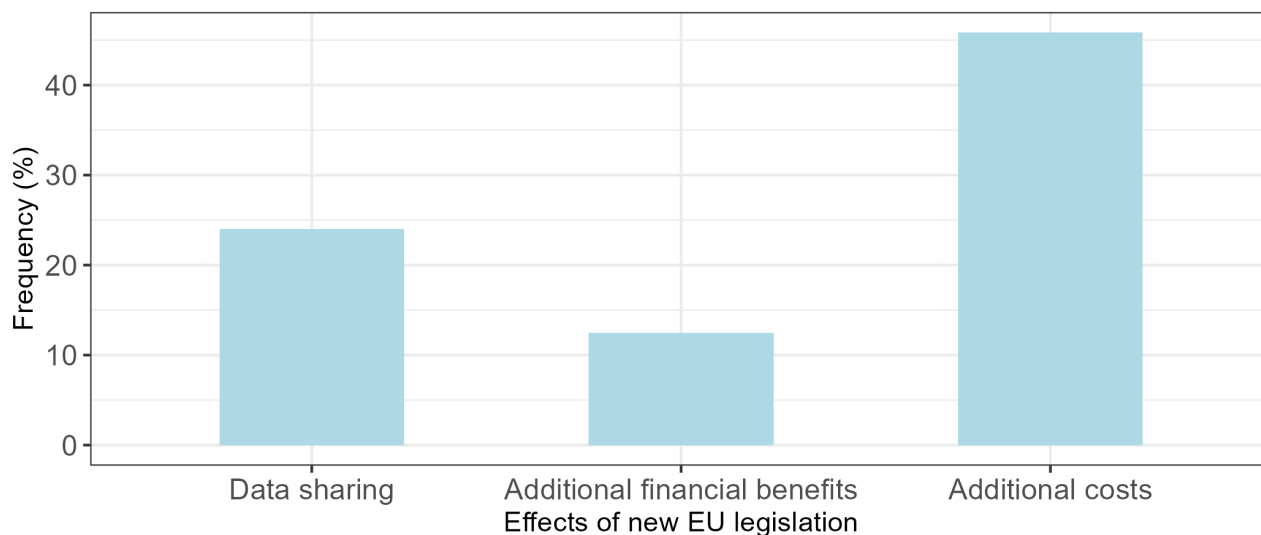
Graph 10: Frequency (%) of conformity assessment activities.

2.2.3.1.5. Data sharing and legislation

The majority of interviewed stakeholders (83.3%) were positive towards data sharing, recognizing benefits for all involved parties. Familiarity with the new EU legislation, and potential effects associated with it are presented in Graphs 11 and 12, respectively. Approximately half of the respondents were familiar with data act, data governance and AI act of the EU legislation (66.7%, 63.9%, and 55.6%, respectively; Graph 11). Amongst those, 76.0% reported that the new EU legislation had not affected their strategy towards data sharing. Moreover, in most cases no additional costs (54.2%) or financial benefits (87.5%) related to the legislation were reported (Graph 12).



Graph 11: Frequency (%) of familiarity with different aspects of the new EU legislation reported by the interviewed stakeholders.



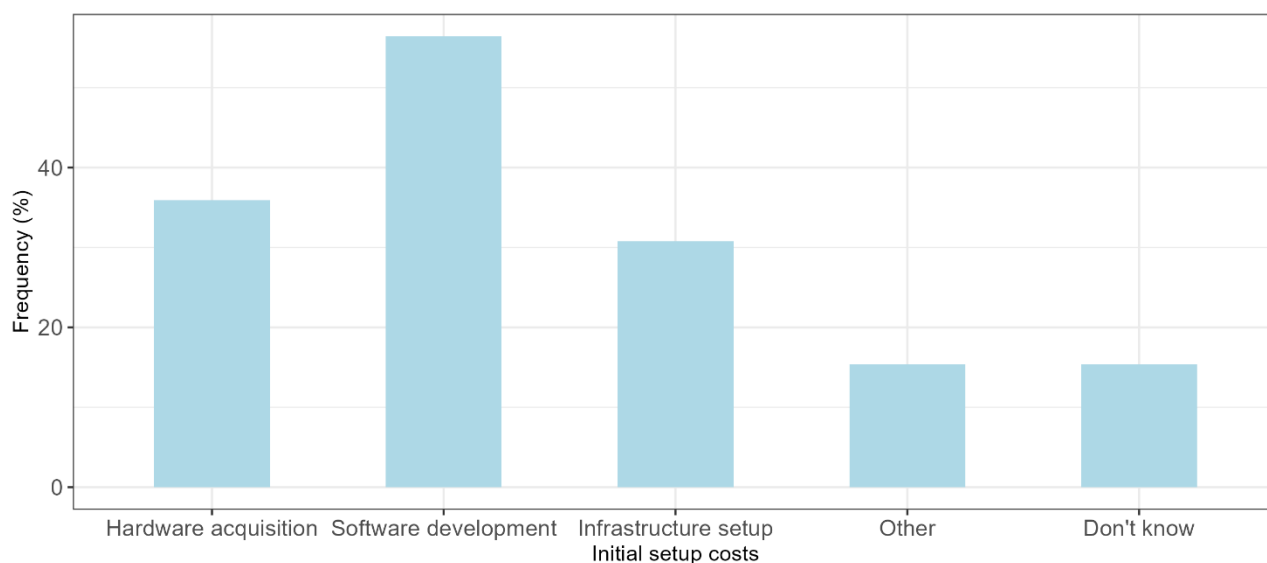
Graph 12: Frequency (%) of effects related to the new EU legislation reported by the interviewed stakeholders.

2.2.3.1.6. Associated costs

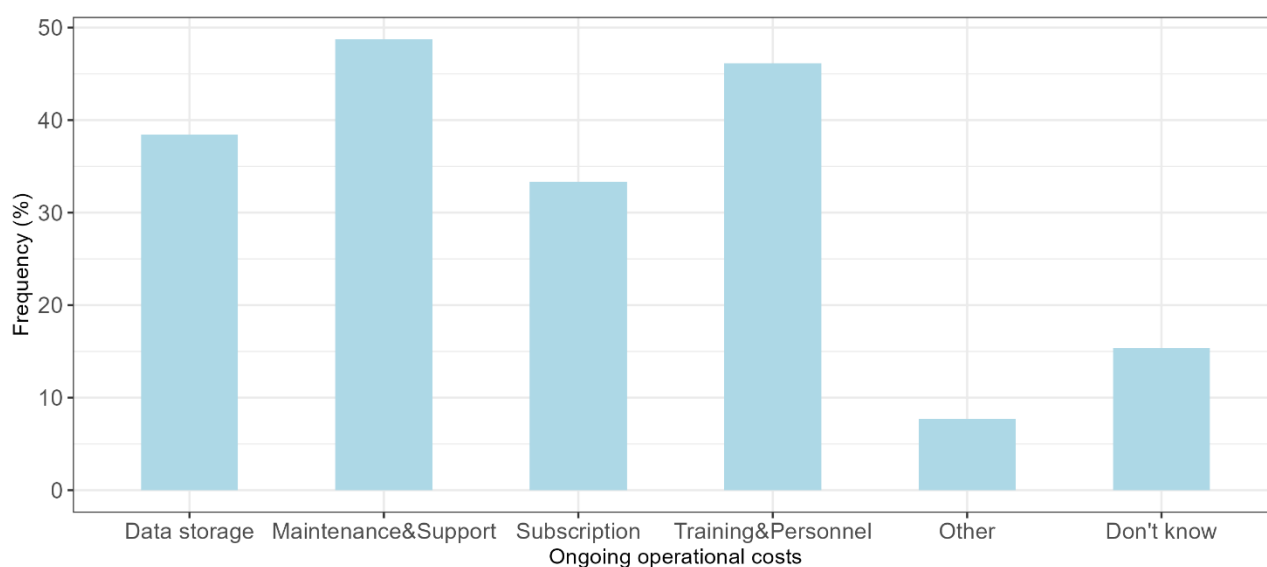
The major initial setup and ongoing operational costs related to the implementation of livestock tracking datasets and tools identified by the stakeholders are presented in Graphs 13 and 14, respectively. Software development was the most frequently reported major initial setup cost (56.4%), followed by hardware acquisition (35.9%) and infrastructure setup (30.8%); 15.4% of the stakeholders indicated other major setup costs (Graph 13) such as data reception, integration, labor, prototyping and language support. In terms of major ongoing operational costs, maintenance and support (48.7%) and training and personnel (46.2%) were the most frequently reported, followed by subscription (33.3%) and other costs (7.7%) such as data sharing

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(Graph 14). Finally, some respondents (15.4%) did not know or did not want to disclose information related to both setup and ongoing operational costs (Graphs 13 and 14, respectively).



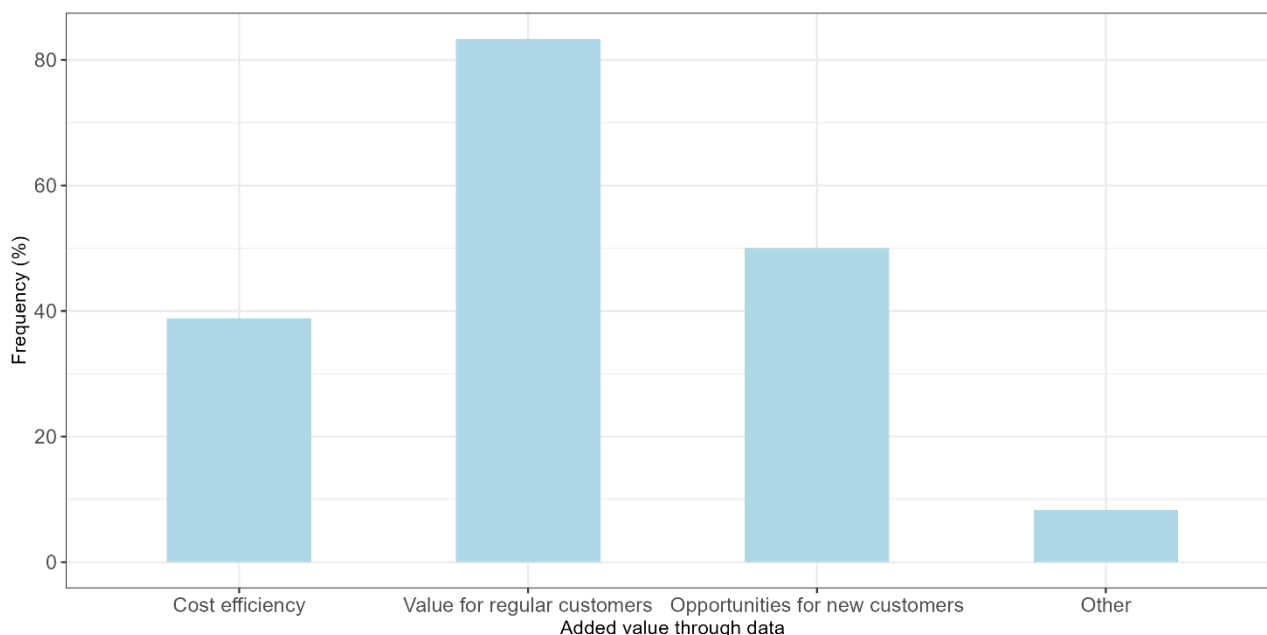
Graph 13: Frequency (%) of major identified initial setup costs related to the implementation of livestock tracking tolls/datasets by the interviewed stakeholders.



Graph 14: Frequency (%) of major identified ongoing operational costs related to the implementation of livestock tracking tolls/datasets by the interviewed stakeholders.

2.2.3.1.7. Data and strategy

Overall, stakeholders were positive towards data usage recognizing added value for their organization (Graph 15). Specifically, data usage enabled them to stay ahead of the competition by understanding and meeting the requirements of their regular customers (83.3%) and creating opportunities for new target groups (50.0%). In some cases, data usage was also mentioned to help towards making certain processes more cost-efficient (38.9%). Other added values identified by some stakeholders (8.3%) included predictive analytics possibilities and reducing administrative workload.



Graph 15: Frequency (%) of added value possibilities through data usage reported by the interviewed stakeholders.

2.2.3.2. Insights per case study

2.2.3.2.1. Case study A

In total 9 interviews were conducted with stakeholders from various sectors in the Netherlands and Germany, including two livestock farmers and cooperatives, four slaughterhouses and retailers, one research institute, and two technology providers/software developers and consultants (AI-software solutions, barcodes). The interviewed stakeholders were selected for their relevance to digital livestock technologies, their experience in using such technologies and CS-A goals.

User requirements

The interviewed stakeholders provided/used tools, datasets and services including AI-driven software solutions, farm management databases, supply chain data, and decision-making services. Provided tools/datasets/services facilitated either alerts for animal health, welfare and behavior indicators or traceability, logistics and scheduling in the food supply chain. Tools were designed to be compatible with existing digitalized farm management systems, while also accommodating manual data inputs, offering flexibility at various levels of technological readiness.

Maturity, planning, implementation strategy

AI-driven software solutions for pig farming were highly advanced, achieving approximately 95%-100% accuracy and adaptable to diverse farm setups, supporting both fully digital systems and those relying on manual inputs. Future plans included expansion of predictive analytic capabilities, focusing on forecasting

health and welfare outcomes based on historical data, as well as AI solutions for other species, such as poultry, dairy cattle, and sheep. Retailers using traceability datasets implemented multiple internal systems for data management and integration processes across their operations. Their data collection included tracking carcass composition, veterinary health data, and CO₂ footprint metrics, which were incorporated into production planning. For enhanced traceability, they used RFID chips in slaughterhouses to link specific animal data with individual carcasses, from farm entry to processing. Planning focused on innovation and continuous improvement.

Needs for standardization

In most cases, alignment with international standards and European legislations were mentioned. Overall, the critical areas identified about standardization included:

- Standardized benchmarks for animal behavior recognition to facilitate consistent and reliable comparisons across farms, improving the value of the insights generated.
- Standardized approaches in data management across the food supply chain particularly for ease of integration and consistency in data-sharing practices.

Conformance and certification

AI-driven software solution providers adhered to EU guidelines and were actively seeking partnerships to validate and certify their algorithms, enhancing credibility among stakeholders. Some retailers implemented robust DNA traceability systems to ensure compliance with animal welfare standards, adding a layer of accountability and building consumer trust.

Data sharing and legislation

Most of the respondent stakeholders were positive regarding data sharing and efforts were made to comply with both market and legal requirements. However, in some cases, reluctance to share data due to competitive disadvantages was mentioned. In all cases, data anonymization was prioritized. Data sharing was mostly hindered by technical, economic, and social barriers. Specifically, the major identified challenges included data standardization, integration and comparison due to diverse data formats, high costs for maintaining and harmonizing data, lack of financial incentives, and mistrust. In some cases, the need for (i) a clearer EU legislation on data sharing that encourages secure, industry-wide cooperation without compromising confidentiality, (ii) a “value chain orchestrator” to mediate data sharing and foster equitable collaboration, and (iii) building trust and ensuring mutual benefits for all parties were highlighted.

Associated costs

Most of the stakeholders did not provide insights regarding major setup and ongoing operational costs. However, in the case of advanced traceability and data security systems significant expenses were acknowledged. Specifically, DNA traceability and RFID tagging processes, as well as blockchain-based CO₂ tracking, were mentioned to require specialized technology and expertise. Moreover, investments in regional programs and potential vertical integration further implied financial considerations aimed at improving data accessibility and traceability within the supply chain.

Data use and strategy

Data was used for various purposes including farm management, animal health and welfare, and traceability in food supply chain. For all responding stakeholders, data was central to decision-making, enabling precision farming, improving sustainability, enhancing traceability, and meeting industry and consumer requirements. Data strategy and associated benefits mainly included maintaining high standards in the supply chain and

fostering transparency, data-driven decision-making that optimizes operations and improves outcomes, improving farm performance, sustainability and market positioning, and staying ahead of market trends and regulatory changes. Data collection automation, common formats for data integration, financial incentives and building trust among parties were considered important to increase data usage in the future.

2.2.3.2.2. Case study B

In total, 10 interviews were conducted including seven persons from public administration, one farmer organization and two major pig transporters in Poland and Denmark. The interviewed organizations were selected for their relevance with digital livestock technologies, CS-B and CS-F as well as other general activities of Digi4Live. They all deal with veterinary and health matters as well as transporting of live animals and use online platforms-portals (based on TRACES system) for animal health certification at provincial, national and European level.

User requirements

Interviewed organizations had tools/datasets/services used for a variety of purposes, but mainly for ensuring livestock supply chains through the integration and effective use of diverse data types in the TRACES system. They all used web-tools, with different focal points. A high priority was on mobile compatibility as a lot of the access and usage occurs remotely. In most cases, there was no need for specific technologies to be used, however an account and internet connection was always required, with all portals requiring at least some amount of training in conjunction with the creation of their account to ensure usability. Interviewed stakeholders evaluated their perceived usefulness and ease of use as high, noting though, that there is also documentation available for users needing more support. Additionally, none of the systems had a direct cost to the user but were funded through levies or national funding.

Maturity, planning, implementation strategy

In all cases more than three updates had been released and plans for future updates were reported. Multiple languages were supported pertaining mainly to Danish and English, but other languages could be considered. Data export was only possible in one of the cases, while its implementation was not in the future plans of other organizations. However, data storage was available indefinitely, or until deletion was required, in all tools/databases. Customization options were not available for any of the systems. One of the interviewed organizations had plans for further customization options in tandem with TRACES NT standardization strategies. Additional plans for further increase and support in data sharing, some small changes to user interface and further automation were reported.

Needs for standardization

The needs for standardization were assessed for 5 different categories (functionality & reliability, compatibility, security, compliance, support and other). The issues and categories with the main standardization needs are presented below:

1. **Data intermediation services** – standardization needs were reported in all 5 categories however compatibility, compliance and reliability were mostly emphasized.
2. **Public administration** – a high need for standardization was reported in all categories besides security, which they found important, but less so.
3. **Transport company** – compatibility and, in that sense, reliability was noted as the most important requirement.

To summarize, the biggest standardization needs, based on discussion with various stakeholders, included compatibility (with different systems, devices, data formats), compliance (data protection, information security, other standards) and reliability.

Conformance and certification

Interviewed organizations mentioned that their system was certified according to the *Danish Transport Standard* and *Danish Product Standard*, while another was accredited and certified according to Council Regulation (EC) No 1/2005 of 22 December 2004. In other cases, compliance with the EU regulations and national regulations and international standards such as those established by the World Organization for Animal Health (WOAH), Codex Alimentarius, or International Plant Protection Convention (IPPC) were reported. The activities involved in the conformity assessment were inspection, verification, validation and certification.

Data sharing and legislation

In general, interviewed organizations had a very positive attitude towards data sharing as it enables better utilization of data and automation of tasks and ensures that relevant authorities, stakeholders, and institutions have timely access to critical information about consignments of animals and animal products. Regarding familiarity with the new EU legislation, all organizations were familiar with the data act and the data governance act, but less so with the AI act (especially concerning how the AI act might change legislation concerning data). None of the responses indicated that the new legislation would change their strategy regarding data sharing. They saw no need to await the legislation if data sharing could improve usability of their tools. Regarding views concerning setup or operational costs, stakeholders had similar opinions. They foresee that the new legislation will bring both additional costs and benefits to their operations as changes in the legislation will almost certainly require a change in their tools/products/services.

Associated costs

All interviewed organizations mentioned that software development and infrastructure were the biggest contributors to the initial setup cost. The biggest ongoing costs for public administration included maintenance/support and training/personnel and for private companies included data storage and management and maintenance/support. It should be noted that none of the interviewed organizations were able to prioritize based on actual costs as they are also integrated in other services. For example, the public administration tool utilizes infrastructure used by other services as well, masking the direct cost.

Data use and strategy

All interviewed organizations perceived data in a central position and foresaw growing data usage in the next 5 years with data sharing being of the utmost importance. They all believed data would add value to the organization, for instance in cost reduction, administrative burden cuts, efficiency improvements or enabling new possibilities. Generally speaking, the Danish interviewees believed that current standardizations and data uses work quite well and help them address their needs. All organizations mentioned that their job would be impossible without the use of TRACES NT data and sharing between the organizations in Denmark. The Danish companies interviewed all shared data with one another to improve efficiency and workflows with data ownership being of less importance as the benefit is for all and cost is being carried by existing funding rather than end-user payment. Moreover, Polish stakeholders mentioned that TRACES handles large volumes of data to support traceability, compliance, and efficiency in trade. The data is used by a variety of stakeholders, including veterinary and phytosanitary authorities, economic operators, and customs officials. Data use and strategy are centered around enhancing traceability, risk assessment, and compliance while facilitating efficient trade. Finally, what still needs to be addressed to use data on a large scale included sensor and general data standardization, a best practice guide or rule book on data sharing and better notice when data standardization changes.

2.2.3.2.3. Case study C

Aligned with CS-C research focus and the major goals of the Digi4Live project, seven companies were involved in this survey. Among the organizations interviewed were a company specializing in agricultural lighting solutions, one providing advanced technologies and equipment for poultry farming, one focused on smart systems for monitoring the respiratory health of pigs, two companies providing GPS technology solutions to track animals outdoor, one company providing an app for grazing management and a cheese producer organization. In general, the interviewed companies provided solutions spanning from holistic system designs for livestock farming to specialized equipment and technologies enhancing animal welfare and health monitoring in real time, for various species (dairy cattle, pigs, poultry).

Regarding policy and administration, interviewed organizations deal with economic and financial data as well as subsidy payments. Data intermediation services provided access to data spaces with various reach (across Europe and country/region specific). Both breeding companies and software producers offered various solutions, depending on the consumer's needs.

User requirements

The interviewed organizations provide specialized digital tools and services for the livestock industry, covering areas such as lighting optimization, poultry management, health monitoring, animal outdoor GPS tracking or grassland management. These tools leverage data-driven and intelligent technologies to support precise management of farming processes, enhancing productivity and optimizing farming outcomes. Most tools are based on modern digital platforms, supporting use on mobile devices, web applications, or cloud platforms, requiring internet connectivity and account login. Most of the tools need the users to input data even if some can be automatically filled. While the ease of use and operational complexity of these tools varied across companies, they were generally well-received, with essential documentation and support resources available to help users get started quickly. The perceived usefulness of the tools was generally very high. The tools primarily operated under proprietary licensing models, requiring subscription or purchase, with some offering free versions for users.

Maturity, planning, implementation strategy

All interviewed companies had released more than three updates and planned to continuously optimize their solutions in the future. While some of the tools supported multiple languages, with language coverage typically tailored to market demands (e.g. Chinese, English, Spanish, etc.; in some cases, approximately 150 languages were supported), some others only supported French or French and English because they are currently mainly dedicated to the French market. However, they mostly planned to support additional languages in the future. Data export, exchange, and storage functionalities were widely available. Each company offered flexible data management options to meet diverse user needs, with some tools emphasizing data processing through integration with external systems. Customization options were widely accessible, enabling personalized solutions for users. Future plans included enhancing automation levels, focusing on the development of closed-loop feedback systems, strengthening integration with third-party systems, and expanding to more application scenarios to further advance the digitalization and intelligent transformation of livestock farming.

Needs for standardization

The interviewed companies exhibited the strongest standardization needs in compatibility (integration with different systems, devices, data formats or telecoms networks) and functionality (reliability and seamless integration, access and GPS location), while the demand for security and compliance varies depending on the maturity of their tools. In general, the core of standardization lied in achieving cross-platform integration and

functional improvements to align with the trends of modern digitalization and intelligent industry transformation.

Conformance and certification

Most companies clearly indicated compliance with national and international standards. Among them, one company specified standards such as ISO 9001 and ISO 27000, while some other companies are uncertain about their compliance. Most companies covered activities such as testing, inspection, validation, and verification. One company demonstrated the most comprehensive assessment, including accreditation and certification. However, some companies were limited to testing activities only. Apart from one company, which explicitly states that certification was provided by manufacturers and test laboratories, the other two companies did not specify their authorized parties.

Data sharing and legislation

All companies had a positive attitude towards data sharing, recognizing the importance of data integration for industry development. However, they also made new suggestions, such as emphasizing the involvement of stakeholders, the necessity of data integration, transparency, and the critical role of data application. Most companies showed greater attention to regulations, demonstrating a deeper understanding of the practical challenges posed by regulations. In contrast, some other companies had relatively limited awareness in this area. Most companies believed that current regulations have no significant impact on their data-sharing strategies, though some companies hold differing opinions, suggesting that regulations might have some influence. Only a few companies anticipated additional setup or operational costs due to regulations, noting that some regulations lack practical applicability. All companies agreed there are no financial benefits.

Associated costs

Different companies had varying perspectives on initial costs with some considering subscription licensing fees as the primary cost, while others software development/procurement as the main investment for initial setup. Different opinions were expressed in terms of the major ongoing operational costs; subscription fees, training personnel, and maintenance and support were reported. This reflects differing priorities across the industry regarding system maintenance, platform reliance, and customization needs.

Data use and strategy

All companies agreed that data occupies a central position in their business, serving as a critical driver for strategic decision-making and operational improvement. They anticipated that the use of data will continue to grow over the next five years with a wide range of uses to help provide answers to the challenges faced by the agricultural and food sectors. These companies also recognized that data could add value to their organizations in various ways, such as cost reduction, reducing and automating administrative tasks, improving operational efficiency, and creating greater value and services for customers. Moreover, data integration and standardization have become a shared priority, aiming to achieve cross-platform and cross-organization data connectivity and value extraction, thereby fostering data-driven innovation and sustainable development.

Achievements in data utilization and integration:

- Integrated farm data to provide high-value insights and support to customers.
- Identified the need for data integration and made progress in advancing large-scale data consolidation.

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- Established infrastructure and data dashboards to effectively support data visualization and management decision-making.
- Automation of data collection, aggregation and storage.
- Production of new services as geofencing, predation detection thanks to predictive models.
- Improve customer relations and services.

Challenges:

1. Trust issues

- Lack of trust among farmers regarding data usage and sharing
- Absence of data-sharing rules weakens inter-organizational trust.
- Concerns over data security and intellectual property loss limiting data sharing.

2. Technical standardization

- Need to enhance global connectivity and data platform integration.
- Urgent need for sensor and general data standardization.
- Lack of unified standards for carbon footprint calculations
- Requires advancing data sharing and technology integration.

3. Other challenges

- Lack of clear data-sharing regulations.
- Data culture issues (e.g., the conservative mindset of farmers) restrict large-scale application.
- Maintenance and consolidation of tools.

2.2.3.2.4. Case study D

A total of 6 interviews were conducted. The organisations interviewed were selected from the genetic improvement sector, so as to be in line with CS-D's activities, by ensuring that there were actors representing the different livestock sectors (ruminants, pigs, poultry and other species) and the different actors linked to digital technology (ruminant genetics interprofession, breeding divisions of technical institutes, genetic data management centres, organisations in charge of genetic evaluation, breeding companies).

For a long time, breeding activities have made a massive use of data, in particular to evaluate the genetic estimated breeding values (EBV) of animals for traits of interest, which are then used to select future breeding stock. For almost 40 years, genetic evaluation methods have been based on the phenotypes of all related animals, and their implementation requires all phenotypes and pedigrees to be centralized. Over the last 20 years, this data has been supplemented by genotype data for genomic evaluation, which is now the reference method.

In the ruminant sector, data for genetic evaluations is collected from several hundred or several thousand of farms, and a fairly complex and highly structured system is required to centralize the data and make the EBV available. In contrast, selection in the poultry sector is carried out on a limited number of dedicated farms, known as selection nuclei. Data still needs to be centralized, but the associated logistics is much less cumbersome and is often internalized by the breeding companies. The situation for pigs is rather similar to that for poultry, but with a slightly greater number of selection nuclei due to the species' lower multiplication capacity.

User requirements

Recent years have marked quite significant developments within each sector, due to the combined effects of changes in the breeding context and regulations, as well as scientific and technological advances.

Changes in the breeding context are leading to major changes in selection objectives, which are increasingly incorporating new traits linked, for example, to environmental impact, health and well-being. These developments are taking place fairly rapidly, and many questions are being asked about the traits being measured, the standardization of measurements, etc.

Technological advances are resulting in a growing number of measurements for purposes that have nothing to do with breeding (precision livestock farming, etc.). It is tempting to want to use this data for genetic improvement purposes, but there may be several obstacles to this use: 1) the data may not be recoverable from the equipment; 2) the measurements may differ from one piece of equipment to another; automated measurements make it possible to obtain longitudinal data which may prove valuable, but technical barriers or a lack of expertise may hinder the use of this high-throughput data.

From a legal perspective, the acknowledgement, in the ruminant sector, of the breeders' ownership of data has required the implementation of systems to obtain breeders' consent to use their data for genetic evaluation purposes. In France, a system based on the blockchain technology has been developed.

In monogastric species, selection using solely data collected in nucleus often appears to be suboptimal and several breeding companies are considering using the performance of crossbred animals in their genetic evaluation. The issues associated with this development are similar to those encountered in the ruminant sector (consent for data use, standardization).

Maturity, planning, implementation strategy

Most of the genetic data pipelines have been operational for several years. They evolve incrementally, at a relatively high frequency (more than three per year). More significant changes may occur to the databases (e.g., the switch from in-house hosting to a service provider to increase efficiency and data security; the introduction of genomic selection, which requires pipelines to be installed to manage genotyping data, and the introduction of the blockchain to obtain breeders' consent). The high frequency of genetic evaluations requires fluid, highly automated information flows. Difficulties are arising in handling new types of data (high-throughput data), for which not all operators are ready today.

Needs for standardization

Conventional phenotypic data is highly standardized, including internationally in certain sectors (via ICAR). Similarly, the conventional data exchange formats are highly standardized and do not pose any major problems. The same applies to genotyping data, which is validated and checked by proven pipelines. The situation is different for data on new traits, particularly when they have been collected for other purposes. There is still a great deal of work to be done on standardizing equipment and measurements, trait definitions, accuracies and data formats. A number of recent attempts to use such data have not necessarily all been conclusive.

Conformance and certification

Conventional measurements carried out on ruminants are subject to accreditation (ICAR standards). Most ruminant data collection processes are certified. The picture is fairly similar for genotyping data, with most analysis laboratories being ISO17025 accredited. The situation is quite different for phenotypic data in pigs and poultry, species in which the quality control processes are internal and do not go as far as accreditation or certification.

Data sharing and legislation

The computation of breeding values requires data to be pooled and therefore shared, in order to be able to manage and store the data securely and to calculate EBVs. However, the data is not open but is used essentially for breeding purposes and is subject to a contractual relationship (consent of the breeders). In monogastric species, the data is in most cases used internally by the breeding company and is not shared, except when the computation of breeding values is outsourced. In this case, the relationships between the breeding organization and the service provider are contractual and guarantee control over data sharing. In some countries, including France, public authorities (ministry of agriculture) require an access to the data of accredited breeding organizations to assess compliance with the specifications required for accreditation and to monitor the genetic diversity of livestock populations (and provide references to international organizations such as FAO).

Associated costs

The biggest initial costs mentioned by the interviewed stakeholders were software development, then infrastructure (including hardware). The biggest ongoing costs mentioned by all stakeholders were associated with maintenance and support, then equally data storage and management and training and personnel.

Data use and strategy

All interviewed stakeholders (with maybe one exception) considered data as essential in their strategy and anticipated an increasing use of data in the next 5 years. The added value for the organization concerned various aspects (e.g. increased cost-efficiency, added value for users, new opportunities).

What works well in utilizing and integrating data: The “standard” procedures associated with EBV computing are necessarily working well.

What still needs to be addressed to use data in a large scale: 1) Standardization and interoperability for new traits ; 2) Ability to manage high throughput data; 3) Regulatory aspects are also mentioned, as well as to clarify the role of the different actors; 4) The question of the rapid staff turnover and the associated difficulty of maintaining skills.

2.2.3.2.5. Case study E

In total, 14 interviews were conducted with stakeholders from various sectors in Greece, including: (a) livestock farmers (5 in total, focusing on pig, sheep and beef cattle production); (b) technology providers (4 in total, offering tools like IoT sensors, RFID readers, and software systems); (c) software developers and consultants (3 in total, providing farm management and data visualization applications) and (d) service providers (2 in total, providing data intermediary and support services). The interviewed stakeholders were selected for their relevance to digital livestock technologies and their experience in using such technologies. Although none of the responding stakeholders was a user of the LCA method for estimating the environmental performance of livestock products (i.e. not directly related to the CS-E), the stakeholders selected are contributors to data sharing and sustainability initiatives in the livestock sector. Thus, their insights into the questions related to the LCA method were considered valuable.

User requirements

The interviewed stakeholders provided/used tools and services including automated systems for feeding, ventilation, temperature control, and milking, animal tracking systems, as well as farm management and data visualization software. For all the respondents, infrastructure such as internet access, mobile compatibility

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and user accounts was commonly required. Stakeholders rated the tools and services highly for ease of use, improving productivity, and decision-making. Most of the farmers emphasized the tools' role in improving efficiency, decision-making, and animal welfare. Licensing varied from proprietary to shareware, with options for customization. Financial incentives and training programs were seen as critical enablers for tool adoption.

Maturity, planning, implementation strategy

The tools provided/used by the responding stakeholders varied in maturity, with some in use for over 15 years. Updates and expansions included plans for enhanced automation (e.g. IoT integration for real time monitoring), broader language support and scalability to international markets. Infrastructure improvements focused on integrating tools with farm management systems and enhancing data export and analysis capabilities.

Needs for standardization

The critical areas identified about standardization were:

- The compatibility with IoT devices, databases, and various software platforms.
- The security and compliance, especially in relation to GDPR and other data protection standards.
- The reliability and technical support for seamless operations.

Standardization in data formats and protocols was a recurring concern among the respondents, with a focus on improving data aggregation and interoperability.

Conformance and certification

Many tools adhered to CE, ISO 9001, and GDPR standards, with conformity assessments including validation, verification, and certification. Some stakeholders highlighted a lack of compliance and expressed interest in future alignment with international regulatory frameworks.

Data sharing and legislation

Data sharing was embraced by most of the respondent stakeholders, particularly for improving the operational efficiency and sustainability in livestock farming. Trust among stakeholders and standardization of data sharing practices were considered as key challenges. Familiarity with EU regulations like the Data Act and AI Act varied among the responding stakeholders. The EU legislation had limited immediate impact on the strategies of the stakeholders' entities but it was seen as a future influencer.

Associated costs

Regarding the setup costs, hardware acquisition, infrastructure setup, and software development were considered as major investments among the responding stakeholders. Regarding the operational costs, data storage, maintenance, and personnel training were noticed. Some of the respondent stakeholders emphasized the need for financial support to offset these costs.

Data use and strategy

For the responding stakeholders, data was central to decision-making, enabling precision farming, improving sustainability, and meeting customer requirements. The following future trends in data use strategy were highlighted by the interviewees:

- a) Increase in the reliance on predictive analytics for optimizing farm operations.
- b) Utilization of data for competitive advantage and regulatory compliance.

- c) Addressing the gaps in data literacy and connectivity for broader adoption.

The farmers specifically planned to leverage data for improving productivity, cost reduction, and achieving sustainability goals.

LCA method for estimation of the environmental performance of livestock products

In total 8 interviewees provided insights into the LCA method, including 5 farmers, 2 technology providers and 1 software developer. Most of them were unfamiliar with the LCA methodology. Awareness of the EU Product Environmental Footprint (EU-PEF) was similarly low. However, when asked about the key requirements for the LCA tools that are developed in the context of CS-E, they provided mobile compatibility, offline modes, customizable templates, and real-time visualization as basic features for such tools, and they indicated the significance of seamless connectivity of such tools with existing IoT and software systems. Efficiency improvements, cost reductions, enhanced regulatory compliance, and progress toward sustainability goals were perceived as benefits of using such LCA tools. The lack of familiarity, data accuracy issues, and high costs of adoption were further perceived as important challenges to overcome for wide use of such LCA tools. Finally, the incentives needed for adopting and integrating such tools into business practices mostly included financial support, technical training and regulatory assistance.

2.2.3.2.6. Case Study F

In total, 6 interviews were conducted. The interviewed organizations were selected based on the relation to CS-F, as well as general activities of Digi4Live project. Among the interviewed organizations were a breeding company, a software producer, two representatives from public administration, and data intermediation services each. In general, interviewed organizations offered various solutions including different application areas (policy & administration, data sharing, production, reproduction & breeding), for various species (dairy cattle, pigs, poultry, or even beyond livestock). Regarding policy and administration, interviewed organizations were dealing with economic and financial data as well as subsidy payments. Data intermediation services offered access to data spaces with various reach (across Europe and country/region specific). Both the breeding company and the software producer offered various solutions, depending on consumer needs.

User requirements

Interviewed organizations had tools/datasets/services used for a variety of purposes. They all used web-tools, but those might be tailored depending on specific used needs. In most cases, there was no need for specific technologies to be used, however an account and internet connection was always required. Perhaps unsurprisingly, the interviewed persons evaluated their perceived usefulness and ease of use as high, noting though, that there is also documentation available for users needing more support.

Maturity, planning, implementation strategy

All interviewed organizations had more than three updates released and had plans to further update their solutions in the future. In most, but not all cases, more than one language was supported. Language support is dependent on country specific settings (e.g. in Finland – Finnish and Swedish are required, in Belgium – Dutch, English and French were used). Data export was always possible, however, data storage depended on services. For instance, a data orchestrator never stores the data but allows easy access to particular information for various actors. Customization options were also widely available. Interviewed organizations had plans for further implementation strategies. For instance, further increase and support in data sharing, expanding availability of services abroad, some small changes to user interface, further digitalization were mentioned.

Needs for standardization

The needs for standardization were assessed for 5 different categories (functionality & reliability, compatibility, security, compliance, support and other). The categories with the highest standardization needs are presented below:

1. **Data intermediation services** – pointed out the importance of standardization in all 5 categories, however most emphasis was put on compatibility and compliance.
2. **Public administration** – noticed need for variables standardization, proper definition, however also pointed out on topics related to compatibility and support (e.g. service management).
3. **Software producer** – the main standardization needs were for compatibility, security and compliance.
4. **Breeding company – similar as for farm management system (compatibility, security and compliance).**

To summarize, the biggest standardization needs, based on discussion with various stakeholders, were for compatibility (with different systems, devices, data formats) and compliance (data protection, information security, other standards).

Conformance and certification

Regarding compliance, interviewed organizations were mentioning:

1. General rules or best practices (e.g. GDPR).
2. ICAR standards (<https://www.icar.org/index.php/icar-recording-guidelines/>).
3. ISO certification (27001, 27002).
4. FADN or FASN standards.

The activities involved in conformity assessment mostly concerned:

1. Verification.
2. Certification.
3. Audits (e.g. by some other organizations, outside companies or higher-level administration).
4. Testing.

Data sharing and legislation

In general, interviewed persons had a positive attitude towards data sharing. Regarding familiarity with new EU legislation, all representatives of private operating companies were familiar with data act, data governance act and AI act. Representatives of public administrations were unaware of changes in legislation concerning data. Regarding questions concerning how strategy for data sharing will be affected by legislation, different answers were received such as that maybe more companies could join data spaces, and that some solutions will be influenced, and data will need to be made available; some respondents admitted that they could not predict the effect. Regarding views concerning setup or operational costs, interviewed stakeholders also shared different opinions. Some data intermediation services perceived the new legislation as both bringing additional costs and benefits to their operations, while others were more hesitant to share their opinions, or admitted there will be no effect.

Associated costs

The biggest initial costs mentioned by the interviewed stakeholders were software development (breeding company, data intermediation services, software producer, public administration), and infrastructure (public administration). The biggest ongoing costs mentioned were data storage and management (breeding, public

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administration), training and personnel (data intermediation services), maintenance and support (software producer, public administration).

Data use and strategy

All interviewed organizations reported data to be in a central position and foresaw growing data usage in the next 5 years. Regarding the possible added value of data usage for the organization, respondents selected more than one option, which suggests that they see various ways of utilizing data, for instance in cost reduction, administrative burden cuts, and efficiency improvements.

What works well in utilizing and integrating data: health data standardization, standardizations within large operators, partnerships within few organizations, and basic data collection.

What still needs to be addressed to use data on a larger scale: trust among farmers (mentioned by four organizations), sensor and general data standardization (mentioned by three organizations), no rule books on data sharing, and lack of common standards for carbon footprint calculations.

2.3. Conclusions

The present report focused on identifying and assessing industrial and research solutions for livestock tracking. Specifically, (i) an inventory of livestock tracking datasets and tools (products, applications, datasets, projects) was created, and (ii) key informant interviews (n=52) with stakeholders (software developers, technology providers industry, public authorities, and research institutions) from nine countries and relevant to the six project CSs were performed to assess their features (user requirements, maturity, planning and implementation strategy, needs for standardization, conformance and certification, data sharing and legislation, associated costs, and data strategy). The Digi4Live inventory is a digital platform providing easy access and navigation to a wide range of livestock tracking tools and datasets. Overall, 378 industry products, applications, datasets and projects related to livestock tracking were identified and included in the inventory; further updates will be performed in the future to include new industry and research solutions. Digital solutions were reported for all animal species, however, the majority of them were used for dairy cows. The most frequent application area was for monitoring animal health and welfare aspects; environment, resilience transparency and traceability, production, and policy-administration application areas were mostly reported in livestock tracking projects. Results from the key informant interviews with stakeholders, suggested that the majority of livestock tracking tools and datasets were highly useful and relevantly easy to use, with major user requirements including data input, account creation, internet access and help documentation. Most of the studied digital solutions had a high maturity level, while future plans mainly focused on further updates, automation, equipment integration, and language support. In most cases, they complied with regulatory standards and had undergone efficient conformity assessment. The major identified standardization needs were related to compatibility, compliance, and security. The biggest initial setup costs were for software development, while ongoing costs were related to maintenance, support and training. Finally, results suggested a positive attitude towards data sharing and added value through data usage was recognized. However, data collection automation and integration, financial incentives and building trust among parties were considered prerequisites to increase data sharing and usage in the future.

3. Gaps & barriers in livestock tracking and recommendations for bridging the gaps

3.1. Background and Objective

The mission of Digi4Live task 2.2 was to identify gaps and barriers in livestock tracking by key informant interviews that were reported in the previous section 2.2 and through a desk research. Moreover, this task was supported by online workshops with stakeholders. Results originating from the desk research and stakeholder workshop are summarized in this section.

3.2. Methodology

3.2.1. Literature review

In the desk review, the following two questions were in focus:

- What are the biggest barriers (gaps) in livestock tracking technologies?
- How could we effectively bridge the gaps in livestock tracking technologies?

In the context of this review, the following definitions were used:

- A gap is an area where more research or development is needed, i.e. a gap represents the space between where we currently stand and where we want to be. In some cases (usually in very novel areas), a knowledge gap can exist without clear or easily identifiable barriers.
- A barrier is an obstacle that actively prevents progress. In our study 'barrier' refers to the limitations which cause gaps. In practice, one could imagine a gap without a barrier. Barrier always relates to a gap.

For the desk study, a protocol to search for information from online publication databases in order to obtain information about gaps and barriers related to livestock tracking technologies was developed. The duties were allocated to the research team so that each thematic issue was examined by a group of experts from one or more partner organizations. The thematic issues examined to identify and analyze existing gaps and barriers were:

- Standardization and interoperability,
- Technical skills,
- Data privacy and security,
- Data quality and robustness, and
- Costs.

First, the group of experts with various backgrounds (precision livestock farming, IT and IP law, economics, production technologies, system analyses, biosystems engineering and livestock production) provided individual contributions on the barriers in livestock tracking for various topics including standardization, interoperability, costs, technical skills, data privacy, security, robustness and quality. Where possible, the individual contributions were supported by relevant evidence from peer-reviewed and grey literature. Second, a narrative was provided on how to effectively bridge these gaps and enable a single European market for livestock data. Finally, conclusions on future research needs were presented.

3.2.2. Online workshops with stakeholders

A co-creation webinar with stakeholders was designed and performed in December 2024. This event served as an introduction to the project, raising awareness of Digi4Live's objectives and laying the groundwork for

a collaborative network with key stakeholders. Within the framework of WP2, it aimed to create an open dialogue that invited the stakeholders' input on potential barriers, and opportunities within the field of digital and data-driven livestock tracking. An invitation was sent to relevant stakeholders representing five target groups, namely (i) farmers, processors and practitioners, (ii) data and digital technology providers, (iii) scientific community, (iv) agri-food DIHs and AKIS actors and (v) other stakeholders.

Altogether 100 stakeholders (not project partners) joined the co-creation webinar, among which 7, 25, 57, 2, and 9 were farmers, processors and practitioners, data and digital technology providers, representatives of the scientific community, agri-food DIHs and AKIS actors and other stakeholders, respectively. Following, presentations related to the projects WPs, poll questions were provided to the stakeholders to gather their input. Specifically, the following poll questions and potential answers related to WP2 were used:

1. Which factor you consider the most important that affects the mainstream use of digital solutions?
 - Hardware & Software.
 - Training & support.
 - Industry.
 - Standardization.
 - Data & strategy.
2. Which is the main gap or/and barrier in livestock tracking?
 - Standardization.
 - Costs.
 - Technical skills.
 - Data privacy & security.
 - Data quality.

3.3. Results

3.3.1. Implementational gaps & barriers in livestock tracking

The results of the review are summarized in Table 7 and briefly elaborated in this section. The references are provided in Table 7. The review identified several gaps and barriers in livestock tracking, the use of data and new technologies. Regarding standardization, the main challenges were related to the lack of standards for technology and performance matrices and fragmentation of technology exploitation, which is reflected also as the lack of big picture in standardization. Moreover, the review suggests that standardization is giving inadequate attention to the specific issues of the livestock sector.

Interoperability is the ability of systems to work together with other systems. This can be achieved by standardization of electrical, mechanical or software interfaces or by implementation of interoperability layers. Regarding interoperability, the main challenges were related to the non-existence of natural data orchestrators and lack of trust between stakeholders. The consequence of the latter aspect is that stakeholders may not be willing to share their data or adopt new solutions, which require sharing their data. Only a limited number of technology companies in the livestock technology sector provide broad API access to their data for the users thus effectively preventing third party interoperability solutions. Although this may be a business strategy, it hinders third parties from efforts to develop more comprehensive solutions. Standardization of livestock technologies is most developed in the dairy sector where ICAR coordinates the creation of standards and guidelines in the area of animal recording, and identification.

There is a digital divide between the high and low technology farms. Several gaps relating to the technical skills, especially gaps in small-scale and more senior farmers' skills were identified. Specifically, farmers are characterized by lack of data management and interpretation skills and difficulty in adapting to user interfaces. Relevant barriers include limited access to training programs, low awareness of improved

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decision-making through data usage, lack of farmer involvement in user interface design, and limited technology integration and interoperability among systems. Also, other stakeholders have knowledge gaps. For example, farm advisors may have inadequate skills to effectively bridge farmer knowledge and skill disparities. In addition, stakeholders do not have a comprehensive view of farmers' perceived ease of use regarding systems. An important gap is also the inadequacy of infrastructures, especially those concerning data connectivity (e.g. mobile network, WIFI, IoT) and easy user support.

The main gaps related to data privacy and security included lack of specific farm data regulations, inadequate trust between actors and security standards. Having reliable and trusted data privacy and security standards and protocols that ensure these standards are complied with is of outmost importance in enhancing the data security and privacy, and farmers' trust towards operators that are managing their data. The lack of regulatory clarity regarding the collection, processing, and sharing of farm data represents an important gap, as it creates challenges in distinguishing what would classify as personal data. Especially with the increasing use of AI techniques, indirect identifiers such as data on farm practices can be used incompatibly for the privacy of farmers, possibly in combination with direct identifiers. Additionally, the EU has adopted important new regulations that may profoundly impact livestock data processing and sharing—namely, the Artificial Intelligence Act (AIA), the Data Governance Act (DGA), and the Data Act (DA)—while also envisioning an agricultural data space. However, these regulations exhibit inconsistencies, including discrepancies in key terms, and there is inadequate guidance, standards and best practices for agricultural technology providers (ATPs) and lack of transparency on ATPs' data handling that may hinder stakeholders' ability control their own data.

Data robustness was also identified as a theme where gaps and barriers exist. The main challenges were related to incompleteness, precision and accuracy of data as well as to the handling of inconsistencies and noise in data and temporal synchronization and interoperability between data systems. In particular, better approaches to validate sensor and data solutions and to handle noise and missing observations in livestock data are needed. Regarding applications, more comprehensive training data is needed to train applications, because this enhances the range of regions and conditions where they can be utilized.

Regarding economic aspects, it is critical to show how much additional value data sharing and new technological solutions can offer to them. The costs of new technology and data sharing can be prohibitive to farmers and stakeholders. In particular, there is uncertainty about the return on investment when new technologies and data-oriented solutions are adopted. Moreover, there are inadequate business models for data sharing. More innovative and synergetic business models could improve the use of data and technologies for livestock tracking.

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Table 7: Summary of existing gaps, barriers and proposed solutions concerning data standardization and interoperability, technical skills, data privacy and security, data quality and robustness, and costs, identified by the review conducted by experts.

Gap	Barrier	Proposed solution
Topic: Data-sharing, standardization and interoperability		
Lack of common standards for sensor technologies and performance matrices.	Fragmented system ¹	Provide clear definitions (e.g. ICAR-IDF initiative). ² Protocols for handling data.
Lack of overview of needs of livestock systems when defining standards.	ISO committees traditionally did not focus on agriculture. “Smart Farming” advisory group seems to focus on crops ³	Start-up subcommittee for different livestock species TAG. ²
Lack of standards in data annotation for livestock applications.		ISO/TC 347 Data-driven agrifood systems. New initiatives, e.g. EAAP working group Sensors and Standards Development for Research Activities.
Lack of innovation in the use of data.	Technology companies do not provide access to data e.g. third-party software developers.	EU data regulation and pressure from stakeholders.
Lack of business models for data sharing business networks. ⁴	Difficulty and high cost of accessing data, and lack of data intermediary services.	Technical solutions to lower the cost and increase fair use of data (e.g. IDSA, GAIA-X).
	Information inequality ⁵ .	Pilot and demonstration projects.
Inconsistency in data collection and management.	Fragmentation of livestock sector, high number of stakeholders ⁶ , and lack of interoperability.	As above.
Topic: Technical skills		
Farmers’ lack of data management and interpretation skills. ⁷	Limited access to training ⁸	Local training focused on data literacy and analytics.
	Low awareness of how data can improve decision-making. ⁹	Demonstration farms to showcase benefits and data-driven decision-making.
	Limited user-friendly tools to visualize & interpret data. ¹⁰	Simple, visual tools for data interpretation.
	Limited technology integration & interoperability in PLF. ¹¹	Increase technology integration.
Farmers’ low ability to operate and maintain various systems. ¹²	Complexity of digital tools and software ¹³ ; User interfaces not designed considering end-users’ views. ¹⁴	Design user-friendly devices with easy setup; localized interfaces with multi-language support.
	Farmers’ difficulty to keep pace with technology ¹⁵ ; resistance to change ¹⁶ , technology discomfort. ¹⁷	Hands-on training during tool deployment.
	Limited access to technical support for troubleshooting ¹⁸ , Excessive training time. ¹⁹	Mobile troubleshooting apps and guides.
		Support hubs, trained technicians, peer-to-peer training.
		Enhance rural connectivity via public-private partnership.

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Farmers' limited understanding of connectivity technologies and inadequate technical infrastructure (WiFi, IoT, ¹⁷).	Poor internet and mobile infrastructure in rural areas ²⁰ ; Low awareness of connectivity's role in technology use. ²¹	Offline-compatible tools. Workshops explaining connectivity's role in improving efficiency in farming. Infrastructure development initiatives.
Limited knowledge of farm advisors on how to effectively bridge farmer knowledge and skill disparities. ²²	Variability in farmers' level of education, digital literacy and technical skills, especially in relation to age and herd/flock size. ²³	International knowledge exchange and farmer cooperation. Training programs especially for low-educated, small-scale farmers by academia and industry. Taking to account user heterogeneity when creating relevant tools and tool automation.
Technology providers' and researchers' limited knowledge on perceived ease of use and usefulness of digital tools. ²⁴	Limited uptake of tools by farmers; Limited involvement of farmers in digital tools' design and assessment. ²⁵	Include farmers in the design process. Promote ease of use.
Topic: Data privacy and security		
	Inconsistencies between GDPR, DGA and DA, and unclarity in their joint implementation.	Consistent reading of and guidance on all these especially in livestock tracking context.
As a result of low transparency and control of data collection and processing by ATPs, farmers are unwilling to share their data with ATPs. ²⁶	The use of indirect identifiers such as data on farm practices can be incompatible with the privacy of farmers, especially if AI techniques are used. ²⁶	Data minimization and security measures. Requiring genuine informed consent from farmers for the processing of personal data. ²⁸
Lack of specific regulations or standards for farm data ²⁷ and wide adoption of such standards and best practices by ATPs. ²⁶		Data Protection Impact Assessment.
Need to strengthen stakeholders' trust for wider technology use and data sharing. ²⁶		Standards and best practices on data privacy and security and data governance.
High degree of discretion that private actors decide on security measures.	EU cybersecurity law is dispersed across several legal instruments. ²⁹	Implementation of appropriate technical and organizational measures (GDPR).
Lack of clear instructions in the regulatory framework for real-world use cases of cyberattacks.	Connected devices involve cybersecurity threats. This could give the ability to third parties to remotely control and exploit on-field sensors. ³⁰	Specific code of conduct for cybersecurity in livestock tracking and farming. Risk assessment.
Need for security standards especially for farmers. ³¹	Security breaches (intentional, unintentional) can be caused by human error, technology or physical threats. ³¹	Raising farmers' awareness about security best practices. ³¹

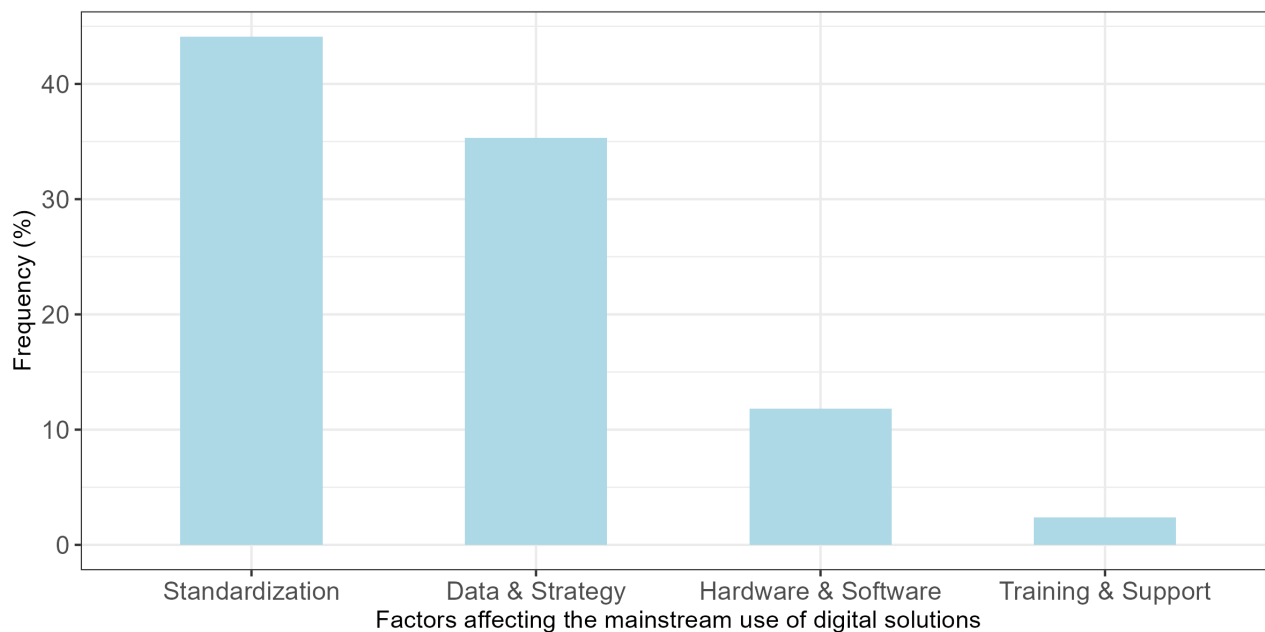
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Topic: Data quality and robustness		
Incomplete data due to sensor failures, connectivity loss, or low battery life. ³⁶	High costs of advanced, reliable sensors, and adapted IOT networks. ³⁶	Enhance energy storing, connectivity, buffer memory; redundancy & interoperability for cross-system validation ³⁶
Lack of best practice guidance in dealing with noise.	High costs of advanced, reliable sensors; lack of proper calibration and maintenance.	Use advanced data preprocessing techniques to clean and correct anomalies.
Precision and accuracy - poorly calibrated sensors or sensor drift. ³⁷	Data analysis strategies effect on data accuracy and precision (statistical vs. machine/deep learning) ³⁹	Regular sensor recalibration and maintenance; on-farm validation for robustness in real conditions. ³⁹
Temporal synchronization and interoperability – Inconsistencies ³⁷	Difficulty in aligning multiple sensor outputs; challenges in ensuring seamless interoperability. ³⁷	Standardized protocols for synchronization. Encouraging interoperability between systems. ³⁷
AI Data Robustness -Limited diversity in training datasets, bias and overfitting. ⁴⁰	High costs and difficulty of collecting diverse, high-quality datasets; over-reliance on quantity rather than quality. ⁴⁰	Follow “Ethics guidelines for trustworthy AI” ³⁵ . Foster shared datasets, incorporate data of various regions and conditions; prioritize variance & quality ⁴⁰
Tool Validation - Incomplete protocols for completeness or repeatability.	Limited on-farm validation and adoption of comprehensive validation protocols.	On-farm validation under variable conditions; Promoting broader validation standards.
Stakeholder Engagement – How data quality impacts farms and stakeholders.	Lack of training and awareness about digital tools and their potential consequences.	Training of farmers and stakeholders; promote clear communication and equipment maintenance.
Topic: Costs		
Uncertainty and limited knowledge on the profitability of investing in tools. ³²	No access to data on economic performance from farms with technology, unsystematic economic evaluations.	Studies to verify claims. Demonstration farms or living labs.
Limited number of farms with technological solutions	High cost of technology. ³³	Promoting open-source solutions.
	Concerns on work required to manage data ³⁴	Scalable systems – test in small-scale before deciding about investment, funding for profitable solutions.
		Training.

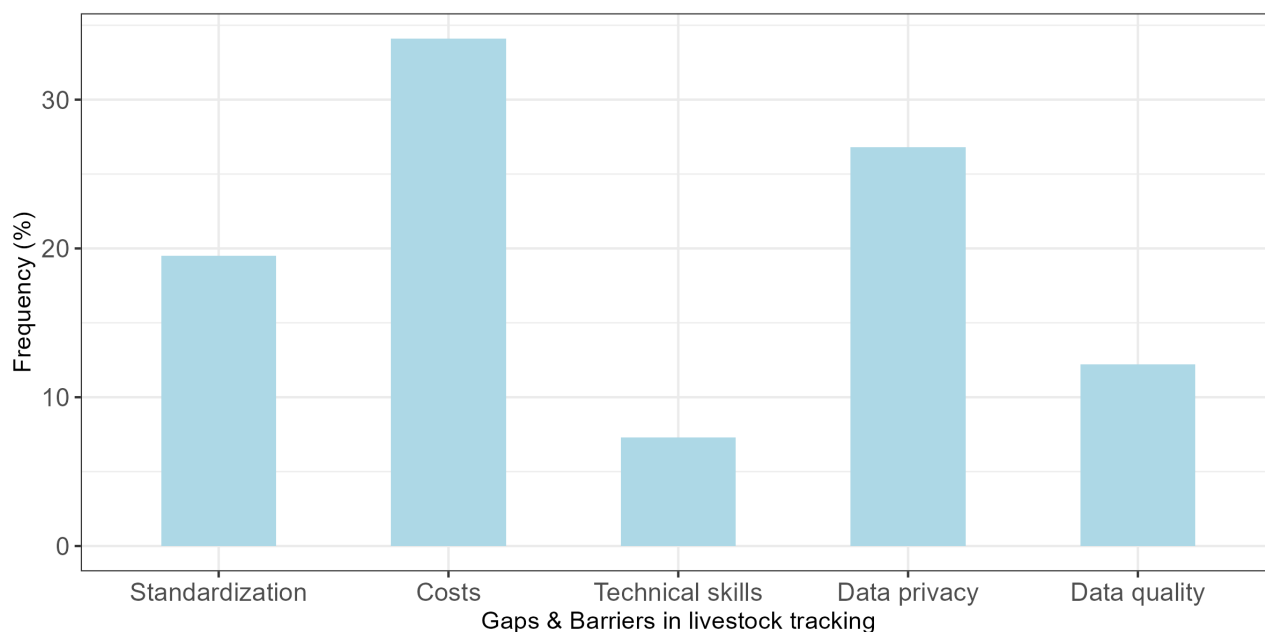
1) e.g. Saint-Cyr et al., 2017; Stygar et al., 2021. 2) Egger-Danner et al., 2024. 3) SAG-SF, 2023. 4) e.g. Krampe et al., 2024. 5) Hackfort, 2021. 6) Williamson and Leonelli, 2023. 7) Bianchi et al., 2022; Drewry et al., 2019; Neethirajan, 2023. 8) Eastwood et al., 2021. 9) Drewry et al., 2019. 10) Bianchi et al., 2022; Henchion et al., 2022. 11) Kopler et al., 2023. 12) Bianchi et al., 2022. 13) Bianchi et al., 2022; Daum et al., 2022; Eastwood et al., 2021; Henchion et al., 2022; Marescotti et al., 2021. 14) Eastwood et al., 2021. 15) Drewry et al., 2019; Higgins and Bryant, 2020. 16) Higgins and Bryant, 2020. 17) Drewry et al., 2019. 18) Bianchi et al., 2022; Eastwood et al., 2021; Higgins and Bryant, 2020. 19) Brier et al., 2020. 20) Drewry et al., 2019; Ferrari et al., 2022; Kaler and Ruston, 2019; Ramirez et al., 2019; Marescotti et al., 2022; Choruma et al., 2024; Fragomeli et al., 2024; Manning, 2024. 21) Fragomeli et al., 2024. 22) Bampasidou et al., 2024. 23) Caffaro et al., 2019; Asmare, 2022; Ferrari et al., 2022; Bampasidou et al., 2024, Choruma et al., 2024; Ohashi et al., 2024. 24) Lima et al., 2018; Michels et al., 2019. 25) Eastwood et al., 2021. 26) Kaur et al., 2022. 27) Kaur et al., 2018. 28) Koolen, 2021. 29) Mantelero et al., 2021. 30) Gupta et al., 2020. 31) Hazrati et al., 2022. 32) Langer et al., 2024; Moyes et al., 2014; Silvi et al., 2021; Steeneveld et al., 2015. 33) Bianchi et al., 2022; Langer et al., 2024; Shutske, 2024. 34) Abeni et al., 2019. 35) AI HLEG, 2018. 36) Mancuso et al., 2023. 37) Selle et al., 2023. 38) Papst et al., 2021. 39) Drenkow et al., 2021, 40) Carraro et al., 2023.

3.3.2. Stakeholders' views

Altogether 34 and 41 responses were provided related to factors affecting the mainstream use of digital solutions and the main gaps and barriers in livestock tracking, respectively. In terms of the former, the most frequently identified factors were standardization (44.1%) and data and strategy (35.3%); hardware and software and training and support were less frequently reported (11.8% and 2.4%, respectively; Graph 16). The major gaps and barriers in livestock tracking according to the respondents were costs (34.1%) and data privacy and security (26.8%), followed by standardization (19.5%), data quality (12.2%) and technical skills (7.3%; Graph 17).



Graph 16: Frequency (%) of major factors affecting the mainstream use of digital solutions reported by the stakeholders that joined the co-creation webinar.



Graph 17: Frequency (%) of major gaps and barriers in livestock tracking reported by the stakeholders that joined the co-creation webinar.

3.3.3. Recommendations on how to effectively bridge the gaps

Based on the review, several recommendations to rectify the current situation were identified (see Table 7). Regarding proposed solutions, several themes were repeated in the discussed topics. For instance, training, communication and demonstration were mentioned as possible solutions for gaps in four topics (cost, technical skills, data privacy and security, quality and robustness). Training programs should be tailored to the needs of different farmers, emphasizing data literacy, analytics, and data-driven decision making. The issues in standardization were also mentioned in data-related themes (data privacy and security, quality and robustness, interoperability). Moreover, to ensure user-friendliness and adoption, farmers could be involved in the design process, to ensure user-friendly, understandable and adoptable outcomes, and hands-on training during tool deployment could be performed to ease.

We suggest that the lack of access to sensor data through APIs or data intermediary services provided by technology companies is the main barrier for data sharing in the livestock sector. Farmers' willingness to share detailed data about their production for fair use at a price is evidenced by different sustainability programs conducting e.g. farm specific LCA or animal welfare assessment across Europe.

Regarding infrastructures, improvement of rural connectivity through public-private partnerships and investments in infrastructure developments was identified as a solution. Emphasis should be also given to offline-compatible tools that could help increase adoption, especially in less favored areas.

Regarding costs and benefits of using solutions, it is imperative to ensure that farmers and other stakeholders are motivated to participate in a data-sharing scheme. Even the best technological solutions may not be adopted if farmers do not have sufficient incentive to use them. Hence, this includes delivering research-based information and demonstrations on the costs and benefits of the scheme, and information that is rooted in local context. This may provide adequate economic incentives for farmers and other stakeholders to join a data-sharing scheme. In particular, new business cases and pressure towards technology companies is needed to gain broader access to data and to fully integrate and utilize existing data sources for a richer result. Advancements in opening the datasets would also promote the adoption of European data spaces.

Technological advances in energy storage, connectivity systems and buffer memories are pivotal in addressing data incompleteness. Redundancy and interoperability enhance data quality by allowing cross-system validation in data cleaning. However, these solutions may raise sensors costs, necessitating a balance between reliability and affordability in tool adoption. Advanced data processing pipelines can detect and correct anomalies (data cleaning).

Many tools are lacking appropriate validation. Recommendations for complete sensor validations are now available but need to be highlighted and broadly adopted. Incorporating data from various conditions and farming practices is instrumental as it allows AI models to generalize better, reduce biases, and adapt to real-world scenarios. This diversity helps mitigate overfitting and improves the system's ability to handle edge cases, such as rare diseases or extreme weather conditions, ensuring broader applicability and reliability.

The results also suggest that there is a need to develop context-specific standards, best practices, and codes of conduct for the stakeholders involved in livestock tracking including, but not limited to farmers and ATPs, on data privacy and (cyber)security, and data governance. Such instruments should assist better implementation of the General Data Protection Regulation (GDPR) rules on, such as, data minimization, data security, genuine informed consent -which is even more important in smart environments, like the smart farms, data protection impact assessments, among others. This needs to be done not only according to the GDPR but also the new regulatory developments – primarily, the EU Data Act and Data Governance Act – and the envisioned agricultural data space.

Regarding solutions specific to certain topics, for data privacy and security it was pointed out that there is a need for updating the code of conduct concerning data sharing. The EU Code of Conduct of Agricultural Data Sharing by Contractual Agreement was published in 2018 (COPA-COGECA, 2018). Recently several improvements have been proposed (Ryan et al., 2024), especially in relation to its future use regarding the response to the Data Act (Data Act, 2023), which is also in line with our findings. In the topic of standardization, the need to support ongoing initiatives and create new bodies (dealing with broader livestock topics) has been expressed.

3.4. Conclusions

The livestock sector generates a lot of data, but the collected data remains underutilized. The EU Data Governance Act and recent technological advances provide an opportunity to automate and improve the collection, integration and use of livestock data. This section examined the main barriers and gaps in livestock digital technologies related to standardization, interoperability, technical skills, data privacy, security, robustness and quality, and costs via a review conducted by expert scientists and a stakeholder workshop. A narrative on how these gaps can be effectively bridged was presented.

To merge existing gaps, multi-tiered solutions are needed (Tier 1: targeted actions by specific actors and Tier 2: broader, value chain initiatives). To close the gaps related to costs, technical skills, data robustness and quality, Tier 1 solutions are essential. These include, for example, improving technical skills through training and further collaboration between farmers, farm advisors, and sensor producers would be recommended. Gaps in standardization, interoperability, privacy and security require a collaborative approach that involves a range of stakeholders as everyone's incentives and mutual consensus are important in order to achieve an impactful result. Trust was directly or indirectly associated with several themes, so initiatives that directly address building trust (e.g. training, communication and demonstration) are important when aiming at wider uptake of digital technologies.

4. References

- Abeni, F., Petrera, F., & Galli, A. (2019). Survey of Italian Dairy Farmers' Propensity for Precision Livestock Farming Tools. *Animals* 9. <https://doi.org/10.3390/ani9050202> WE - Science Citation Index Expanded (SCI-EXPANDED).
- AI HLEG (2018). High-Level Expert Group On Artificial Intelligence (AI HLEG), Set up by the European Commission. Ethics guidelines for trustworthy AI. <https://digital-strategy.ec.europa.eu/en/library/ethics-guidelines-trustworthy-ai>
- Asmare, B. (2022). A Review of Sensor Technologies Applicable for Domestic Livestock Production and Health Management. *Advances in Agriculture* 2022, 1599190–1599190. <https://doi.org/10.1155/2022/1599190>.
- Bampasidou, M., Goldgaber, D., Gentimis, T., & Mandalika, A. (2024). Overcoming 'Digital Divides': Leveraging higher education to develop next generation digital agriculture professionals. *Computers and Electronics in Agriculture* 224, 109181–109181.
- Bianchi, M., Bava, L., S, rucci, A., Tangorra, F., Tamburini, A., Gislon, G., & Zucali, M. (2022). Diffusion of precision livestock farming technologies in dairy cattle farms. *Animal* 16. <https://doi.org/10.1016/j.animal.2022.100650>.
- Brier, D., Eastwood, C.R., Dela Rue, B.T., & Viehland, D.W. (2020). Foresighting for Responsible Innovation Using a Delphi Approach: A Case Study of Virtual Fencing Innovation in Cattle Farming. *Journal of Agricultural and Environmental Ethics* 33, 549–569. <https://doi.org/10.1007/s10806-020-09838-9>.
- Carraro, A., Saurio, G., & Marinello, F. (2025). Towards rigorous dataset quality standards for deep learning tasks in precision agriculture: A case study exploration. *Smart Agricultural Technology* 10, 100721.
- Caffaro, F., & Cavallo, E. (2019). The Effects of Individual Variables, Farming System Characteristics and Perceived Barriers on Actual Use of Smart Farming Technologies: Evidence from the Piedmont Region, Northwestern Italy. *Agriculture* 9. <https://doi.org/10.3390/agriculture9050111>.
- Choruma, D.J., Dirwai, T.L., Mutenje, M.J., Mustafa, M., Chimonyo, V.G.P., Jacobs-Mata, I., & Mabhaudhi, T. (2024). Digitalisation in agriculture: A scoping review of technologies in practice, challenges, and opportunities for smallholder farmers in sub-saharan africa. *Journal of Agriculture and Food Research* 18, 101286–101286. <https://doi.org/10.1016/J.JAFR.2024.101286>.
- Comtois, D. (2022). summarytools: Tools to Quickly and Neatly Summarize Data. R package version 1.0.1.
- Data Act (2023). Regulation (EU) 2023/2854 of the European Parliament and of the Council of 13 December 2023 on harmonised rules on fair access to and use of data and amending Regulation (EU) 2017/2394 and Directive (EU) 2020/1828.
- Daum, T., Ravichandran, T., Kariuki, J., Chagunda, M., & Birner, R. (2022). Connected cows and cyber chickens? Stocktaking and case studies of digital livestock tools in Kenya and India. *Agricultural Systems* 196, 103353–103353. <https://doi.org/10.1016/J.AGSY.2021.103353>.
- Drenkow, N., Sani, N., Shpitser, I., & Unberath, M. (2021). A systematic review of robustness in deep learning for computer vision: Mind the gap?. arXiv preprint arXiv:2112.00639.
- Drewry, J.L., Shutske, J.M., Trechter, D., Luck, B.D., & Pitman, L. (2019). Assessment of digital technology adoption and access barriers among crop, dairy and livestock producers in Wisconsin. *Computers and Electronics in Agriculture* 165, 104960–104960. <https://doi.org/10.1016/J.COMPAG.2019.104960>.

D2.1 Relevant products & applications of digital technologies for livestock tracking, identified gaps & barriers and recommendations for bridging the gaps

Eastwood, C.R., Edwards, J.P., & Turner, J.A. (2021). Review: Anticipating alternative trajectories for responsible Agriculture 4.0 innovation in livestock systems. *Animal* 15, 100296–100296. <https://doi.org/10.1016/J.ANIMAL.2021.100296>.

Egger-Danner, C., Klaas, I., Brito, L.F., Schodl, K., Bewley, J.M., Cabrera, V., Haskell, M., Iwersen, M., Heringstad, B., Stock, K.F., Stygar, A.H., Van Der Linde, R., Hostens, M., Charfeddine, N., Gangler, N., & Vasseur, E. (2024). Improving animal health and welfare by using sensor data in herd management and dairy cattle breeding—A joint initiative of ICAR and IDF. In *Proceedings of the 11th European Conference on Precision Livestock Farming, Bologna, Italy, 9–12 September 2024* 55–63.

Ferrari, A., Bacco, M., Gaber, K., Jedlitschka, A., Hess, S., Kaipainen, J., Koltsida, P., Toli, E., & Brunori, G. (2022). Drivers, barriers and impacts of digitalisation in rural areas from the viewpoint of experts. *Information and Software Technology* 145, 106816–106816. <https://doi.org/10.1016/J.INFSOF.2021.106816>.

Fragomeli, R., Annunziata, A., & Punzo, G. (2024). Promoting the Transition towards Agriculture 4.0: A Systematic Literature Review on Drivers and Barriers. *Sustainability* 16. <https://doi.org/10.3390/su16062425>.

Franco, L., Justo, A., Coteló, C., Arias, I., Garrido, L., Lloret, L., & Rodríguez-Aubó, N. (2019). Multi-actor engagement: An open innovation process of knowledge exchange and co-creation. In *ICERI2019 Proceedings* (pp. 3808–3813). IATED.

Gupta, M., Abdelsalam, M., Khorsandroo, S., & Mittal, S. (2020). Security and Privacy in Smart Farming: Challenges and Opportunities. *IEEE Access* 8, 34564–34584. <https://doi.org/10.1109/ACCESS.2020.2975142>.

Hackfort, S. (2021). Patterns of Inequalities in Digital Agriculture: A Systematic Literature Review. *Sustainability* 13, 12345. <https://doi.org/10.3390/su132212345>
Hazrati, M., Dara, R., & Kaur, J. (2022). On-Farm Data Security: Practical Recommendations for Securing Farm Data. *Front. Sustain. Food Syst.* 6, 884187. <https://doi.org/10.3389/fsufs.2022.884187>.

Henchion, M.M., Regan, Á., Beecher, M., & MackenWalsh, Á. (2022). Developing ‘Smart’ Dairy Farming Responsive to Farmers and Consumer-Citizens: A Review. *Animals* 12. <https://doi.org/10.3390/ani12030360>.

Higgins, V., & Bryant, M. (2020). Framing Agri-Digital Governance: Industry Stakeholders, Technological Frames and Smart Farming Implementation. *Sociologia Ruralis* 60, 438–457. <https://doi.org/10.1111/soru.12297>.

Kaler, J., & Ruston, A. (2019). Technology adoption on farms: Using Normalisation Process Theory to understand sheep farmers’ attitudes and behaviours in relation to using precision technology in flock management. *Preventive Veterinary Medicine* 170, 104715–104715. <https://doi.org/10.1016/J.PREVETMED.2019.104715>.

Kaur, J., Hazrati Fard, S.M., Amiri-Zarandi, M., & Dara, R. (2022). Protecting farmers’ data privacy and confidentiality: Recommendations and considerations. *Front. Sustain. Food Syst.* 6, 903230. <https://doi.org/10.3389/fsufs.2022.903230>.

Koolen, C. (2021). Transparency and Consent in Data-Driven Smart Environments. *European Data Protection Law Review* 7, 174–189. <https://doi.org/10.21552/edpl/2021/2/7>.

Kopler, I., Marchaim, U., Tikász, I.E., Opaliński, S., Kokin, E., Mallinger, K., Neubauer, T., Gunnarsson, S., Soerensen, C., Phillips, C.J.C., & Banhazi, T. (2023). Farmers’ Perspectives of the Benefits and Risks in Precision Livestock Farming in the EU Pig and Poultry Sectors. *Animals* 13. <https://doi.org/10.3390/ani13182868>.

D2.1 Relevant products & applications of digital technologies for livestock tracking, identified gaps & barriers and recommendations for bridging the gaps

- Krampe, C., Ingenbleek, P.T.M., Niemi, J.K., & Serratosa, J. (2024). Designing precision livestock farming system innovations: A farmer perspective. *Journal of Rural Studies* 111, 103397. <https://doi.org/10.1016/j.jrurstud.2024.103397>.
- Langer, G, Schulze, H., & Kühn, S. (2024). From intentions to adoption: Investigating the attitudinal and emotional factors that drive IoT sensor use among dairy farmers. *SMART AGRICULTURAL TECHNOLOGY* 7. <https://doi.org/10.1016/j.atech.2024.100404>.
- Lima, E., Hopkins, T., Gurney, E., Shortall, O., Lovatt, F., Davies, P., Williamson, G., & Kaler, J. (2018). Drivers for precision livestock technology adoption: A study of factors associated with adoption of electronic identification technology by commercial sheep farmers in England and Wales. *PLOS ONE* 13, e0190489.
- Mancuso, D., Castagnolo, G., & Porto, S. M. (2023). Cow Behavioural Activities in Extensive Farms: Challenges of Adopting Automatic Monitoring Systems. *Sensors*, 23(8), 3828.
- Mantelero, A., Vaciago, G., Samantha Esposito, M., & Monte, N. (2021). The common EU approach to personal data and cybersecurity regulation. *International Journal of Law and Information Technology* 28, 297–328. <https://doi.org/10.1093/ijlit/eaab021>.
- Manning, L. (2024). Innovating in an Uncertain World: Understanding the Social, Technical and Systemic Barriers to Farmers Adopting New Technologies. *Challenges* 15. <https://doi.org/10.3390/challe15020032>.
- Marescotti, M.E., Demartini, E., Filippini, R., & Gaviglio, A. (2021). Smart farming in mountain areas: Investigating livestock farmers' technophobia and technophilia and their perception of innovation. *Journal of Rural Studies* 86, 463–472.
- Michels, M., Bonke, V., & Musshoff, O. (2019). Understanding the adoption of smartphone apps in dairy herd management. *Journal of dairy science* 102, 9422–9434.
- Moyes, K.M., Ma, L., McCoy, T.K., & Peters, R.R. (2014). A survey regarding the interest and concern associated with transitioning from conventional to automated (robotic) milking systems for managers of small-to medium-sized dairy farms. *Professional Animal Scientist* 30, 418–422. <https://doi.org/10.15232/pas.2014-01327>.
- Neethirajan, S. (2023). Artificial Intelligence and Sensor Technologies in Dairy Livestock Export: Charting a Digital Transformation. *Sensors* 23. <https://doi.org/10.3390/s23167045>.
- Ohashi, T., Saijo, M., Suzuki, K., & Arafuka, S. (2024). From conservatism to innovation: The sequential and iterative process of smart livestock technology adoption in Japanese small-farm systems. *Technological Forecasting and Social Change* 208, 123692–123692.
- Papst, F., Schodl, K., & Saukh, O. (2021, November). Exploring co-dependency of iot data quality and model robustness in precision cattle farming. In *Proceedings of the 19th ACM Conference on Embedded Networked Sensor Systems* (pp. 433-438).
- Ramirez, B.C., Xin, H., Halbur, P.G., Beermann, D.H., Hansen, S.L., Linhares, D.C.L., Peschel, J.M., Rademacher, C.J., Reecy, J.M., Ross, J.W., Shepherd, T.A., & Koltes, J.E. (2019). At the Intersection of Industry, Academia, and Government: How Do We Facilitate Productive Precision Livestock Farming in Practice? *Animals* 9. <https://doi.org/10.3390/ani9090635>.
- Ryan, M., Atik, C., Rijswijk, K., Bogaardt, M.-J., Maes, E., & Deroo, E. (2024). The future of agricultural data-sharing policy in Europe: stakeholder insights on the EU Code of Conduct. *Humanities and Social Sciences Communication* 11, 1197. <https://doi.org/10.1057/s41599-024-03710-1>.
- SAG-SF (2023). Strategic advisory group report on smart farming. Final report with recommendations 1–174.

D2.1 Relevant products & applications of digital technologies for livestock tracking, identified gaps & barriers and recommendations for bridging the gaps

Saint-Cyr, L., Latruffe, L., & Piet, L. (2017). Farm Fragmentation, Performance and Subsidies in the European Union. HAL.

Selle, M., Spieß, F., Visscher, C., Rautenschlein, S., Jung, A., Auerbach, M., ... & Distl, O. (2023). Real-Time Monitoring of Animals and Environment in Broiler Precision Farming—How Robust Is the Data Quality?. *Sustainability*, 15(21), 15527.

Shutske, J. (2024). Dairy farms adopt digital tools, but barriers exist to expand tech use. <https://www.agproud.com/articles/21387-dairy-farms-adopt-digital-tools-but-barriers-exist-to-expand-tech-use>.

Silvi, R., Pereira, L., Paiva, C., Tomich, T., Teixeira, V., Sacramento, J., Ferreira, R., Coelho, S., Machado, F., Campos, M., & Dorea, J. (2021). Adoption of Precision Technologies by Brazilian Dairy Farms: The Farmer's Perception. *Animals* 11. <https://doi.org/10.3390/ani11123488> WE - Science Citation Index Expanded (SCI-EXPANDED).

Steenefeld, W., Hogeveen, H., & Lansink, A. (2015). Economic consequences of investing in sensor systems on dairy farms. *Computers and Electronics in Agriculture* 119, 33–39. <https://doi.org/10.1016/j.compag.2015.10.006> WE - Science Citation Index Expanded (SCI-EXPANDED) WE - Social Science Citation Index (SSCI).

Stygar, A.H., Gómez, Y., Berteselli, G.V., Dalla Costa, E., Canali, E., Niemi, J.K., Llonch, P., & Pastell, M. (2021). A Systematic Review on Commercially Available and Validated Sensor Technologies for Welfare Assessment of Dairy Cattle. *Frontiers in Veterinary Science* 8, 177. <https://doi.org/10.3389/fvets.2021.634338>.

Wickham, H. (2016). *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag New York.

Williamson, H.F., Leonelli, S. (Eds.), 2023. *Towards Responsible Plant Data Linkage: Data Challenges for Agricultural Research and Development*. Springer International Publishing, Cham. <https://doi.org/10.1007/978-3-031-13276-6>.

5. Annex

5.1. Annex 1 - Structured interview questionnaire



Assessing Livestock Tracking Tools, Datasets & Services Questionnaire

General

Date

Company

Country

Tool(s)/Dataset(s) name(s)

Type(s)

Please indicate from: Product, Application, Database

Short description

Application area

*Please indicate from: Animal health/welfare, Production, Resilience,
Transparency & Traceability, Animal tracking, Reproduction & Breeding,
Feed intake & Grazing, Environment, Policy & Administration,
Data sharing/data platforms/data intermediate services*

Animals

Please indicate from: Dairy Sheep/Goats, Dairy Cows, Meat Sheep, Beef Cattle, Pigs, Poultry, Any

User requirements

For what purpose is the tool/database/service used?

Do users need to input data to use the tool/database/service?

D2.1 Relevant products & applications of digital technologies for livestock tracking, identified gaps & barriers and recommendations for bridging the gaps

*Please indicate yes or no, and if yes please specify
the type of data and if they are inputted manually*

*If data are needed, can some be automatically filled to reduce time & amount of data en
Please indicate yes or no*

On what devices/platforms is the tool/database/service used?

What type of technology/equipment does the user need to have available?

Do users need to create an account and login to use the data?

Please indicate yes or no

Do users need internet connection or signal to use the tool/database/service?

Please indicate yes or no

Do users need help documentation to use the tool/database/service?

Please indicate yes or no

Is help documentation available?

Please indicate yes or no

Do users need any additional materials/information to use the tool/database/service?

Please indicate yes or no, and if yes please specify

What type of payment model is available to users for the tool/database/service?

Please indicate one or more options from the following

Free premium (free with paid premium features)

Open source (optional donations or paid support)

One-time purchase

Annual subscription

Monthly subscription

Pay-per-use Licence-based (e.g. per use, seat, device)

Consumption-based (e.g. pay for the amount of data processed/stored)

Enterprise pricing (custom pricing based on company size or usage)

Other (please specify)

What type of license is available to users for the tool/database/service?

Please indicate one or more options from the following

Proprietary (users need to purchase/subscribe and cannot modify/distribute/resell)

Open source (users can freely use, modify and distribute)

Freeware (users can use it for free but cannot modify or distribute)

Shareware (users can download and use for free for a limited period)

Public domain (anyone can use, modify, and distribute it without cost/permission)

Freemium (free version with basic features & paid version with advanced features)

Please indicate any other user requirements for your tool/database

Please indicate how much do you agree with the following statements regarding perceived usefulness and easy of use of your tool/database/service

7 -extremely agree, 6-quite agree, 5-slightly agree, 4-neither agree nor disagree

3 -slightly disagree, 2-quite disagree, 1 -extremely disagree

Perceived usefulness

Helps to accomplish tasks more quickly

--

Improves job performance

Increases productivity

Enhances effectiveness

It is useful

Perceived ease of use

Easy to learn how to use it

Clear and understandable

Easy to become skillful at using it

Easy to use

Maturity, Planning, Implementation Strategy

How many updates have been released until today?

One

Two

Three

More than three

Do you plan to release more updates?

Please indicate yes or no and specify the implementation strategy

--

Please indicate the level of automation of your tool/database?

Please indicate from the following options

Fully automated

Partially automated

Not automated

Do you plan to integrate (further) automation in the future?

Please indicate yes or no

--

Does the tool/database support multiple languages?

Please indicate yes or no, and if yes please specify

--

Do you plan to support more languages in the future?

Please indicate yes or no and specify the implementation strategy

Is equipment (hardware or software) integration available?

Please indicate yes or no.

If no, do you plan to support equipment integration in the future?

Please indicate yes or no and specify the implementation strategy

Is it possible to export or exchange data?

Please indicate yes or no.

If no, do you plan to support data export or exchange in the future?

Please indicate yes or no and specify the implementation strategy

Is it possible to store data?

Please indicate yes or no and if yes, please also specify for how long.

If no, do you plan to support data storage in the future?

Please indicate yes or no and specify the implementation strategy

Are customization options available?

Please indicate yes or no.

If no, do you plan to support custom-capabilities in the future?

Please indicate yes or no and specify the implementation strategy

Please indicate if you have other plans and their implementation strategy.

Needs for standardisation

Please rate the following items from 1 to 5 in terms of need for standardization

5 =high, 1 =low

Functionality & Reliability (technical & quality management system)

Compatibility (with different systems, devices, data formats)

Security (controls, risks, cybersecurity and privacy protection)

Compliance (data protection, information security, other standards)

Support (service management, communication protocols)

Other (please specify and rate)

Please describe the standardization needs, if any, for the following aspects

1-Functionality

2-Compatibility

3-Security

4-Compliance

1-Support

2-Other needs for standardization

Conformance and Certification

Does the tool/database/service comply with national/international regulatory standard

Please indicate yes or no, and specify which are these standards

Please indicate the activities involved in conformity assessment

Testing

Inspection

Validation

Verification

Accreditation

Certification

Other (please specify)

Please indicate the authorized party that provided the certificate?

Manufacturer

Test laboratory

Other (please specify)

Data sharing & Legislation

What is your strategy towards data sharing? Do you see the need to obtain data from other systems or potential for others to benefit from your data?

Please indicate yes or no, and if yes please specify

Are you familiar with the new EU legislation?

Please indicate yes or no regarding the following aspects

Data act

Data governance act

AI act

If yes, has the legislation affected your strategy to data sharing?

Please indicate yes or no, and if yes please specify

--

Are you expecting any additional setup (for new products) or operational (for existing products) costs related to the new legislation?

Please indicate yes or no, and if yes please specify

--

Are you expecting any additional financial benefits related to the legislation?

Please indicate yes or no, and if yes please specify

--

Associated Costs

Which are currently the biggest initial setup costs related to the implementation of tools/datasets/services for animal tracing and tracking:

Please indicate from the following options

Hardware acquisition

Software development/Procurement

Infrastructure setup

Other (please specify)

I don't know/I don't want to disclose

Which are currently the biggest ongoing operational costs related to the implementation of tools/datasets/services for animal tracing and tracking:

Please indicate from the following options

Data storage and management

Maintenance and support

Subscription

Training and personnel

Other (please specify)

I don't know/I don't want to disclose

Data & Strategy

What role does data play in your current firm strategy?

How do you envisage the use of data in the next five years?

How can you use data to stay ahead of the competition? Chain integration

In general, how can data add value to your organisation?

1) By making certain processes more cost-efficient (of so, which, how?)

2) By becoming more valuable for our regular customers/users/beneficiaries (which, how?)

3) By creating new opportunities for new customer/user groups (because the data have something

4) By any other way (please describe)?

How can data justify your (managerial) actions?

How is data used to adjust management decisions?

What do you think is already working well in integrating and utilising data?

*What issues do you think still need to be urgently addressed in order to implement and u
(lack of trust, data-based connectivity, lack of harmonisation/standardisation, data agg*

5.2. Annex 2 - Written communication with stakeholders (case study E example)

Digi4Live (HorizonEurope Research Project) aims to identify the already available industry products, applications, datasets, projects, and initiatives related to livestock tracking and digital technologies. Evaluation criteria are developed to screen these identified products, and a database is created to store this information, supplemented by data obtained from relevant stakeholders.

To further obtain in-depth knowledge, a structured questionnaire was prepared to systematically collect information from relevant stakeholders on datasets and tools, covering issues such as technology and user requirements, maturity, planning, implementation strategy, needs for standardization, conformance, and certification.

In addition, Digi4Live aims to provide technical support to parties to develop innovative technologies in 6 case studies elaborating new datasets in animal health & welfare, upscaling & new data sources for sensor technologies, enhancing value chain resilience & transparency as well as environmental impacts assessment, integration of different technologies incl. animal breeding, and supporting data and digital solutions in policy & impact monitoring and administration with competent authorities of all EU member states.

In the context of the environmental impact assessment case study, user-friendly, web-based templates for importing primary data at the livestock farm level, specifically focusing on intensive pig and poultry farms are currently developed. A prototype software will also be developed using the imported data to generate life cycle inventory (LCI) datasets, facilitating the assessment of the environmental impact of these farms, in compliance with the EU's Product Environmental Footprint (PEF) method. This case study intends to facilitate the implementation of environmental Life Cycle Assessment (LCA) of livestock products' supply chains. To engage stakeholders more relevant to this case study, the questionnaire was enriched with questions related to the application of LCA on an organization level.

