Drivers and barriers of digitalisation in Hungarian pasture-based beef cattle farming

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Abstract: This study, conducted within the HORIZON Europe PATH2DEA project, examined the drivers, barriers, trends, and risks of digitalisation in pasture-based beef cattle farming in Hungary, with a focus on its potential to support agroecological practices and Precision Livestock Farming (PLF) approaches. Two stakeholder workshops were held. Workshop 1 mapped current digital tool usage and identified transparency, decision support, and efficiency as main adoption drivers, while highlighting barriers such as vulnerability to suppliers, limited network access, and high costs. Workshop 2 focused on functional gaps at farm and supply chain levels, revealing needs for more reliable sensor technologies, improved interoperability, and streamlined administration. Stakeholder views on the agroecological benefits of digitalisation varied, reflecting differences in context and priorities. The findings provide a concise evidence base for developing integrated, context-specific digital solutions to support sustainable livestock production.

Keywords: PLF, digitalisation, agroecology, beef cattle

Introduction

The present study was conducted as part of the HORIZON Europe project "PATH2DEA - *Paving the Way towards Digitalisation Enabling Agroecology for European Farming Systems* (Grant Agreement No. 101060789, EU & 22.00535, SERI; PATH2DEA, 2023), which aims to harness the potential of digitalisation to support the transition of European agriculture towards greater sustainability, building on farmers' knowledge and needs. Six showcases from different pedo-climatic regions provide practical insights to promote the adoption of digital agroecological solutions and to validate the project's outcomes. One of these six showcases is hosted by the Hungarian Research Institute of Organic Agriculture (ÖMKi), which, in addition to conducting its own research in the field, also collected data from Hungarian pasture-based beef cattle farms related to the topic.

The digital transformation of agriculture has the potential to substantially enhance the sector's efficiency, sustainability, and productivity through the integration of advanced technologies. Tools such as precision farming, the Internet of Things (IoT), and blockchain are increasingly applied not only in conventional agriculture but also in organic, agroecological, and regenerative farming systems. These innovations enable more efficient and conscious resource use, reduce environmental impacts, and optimize yields (Zhang and Kovacs, 2012; Finger et al., 2019).

Agroecology, as a holistic approach that builds upon and optimizes ecological processes to support agricultural production, aligns well with this ongoing digital transformation. By fostering stronger synergies with nature and ecosystem services, agroecological systems enhance farm circularity, diversification, and autonomy. In doing so, they can also stimulate far-reaching transformations in farming systems and agri-food value chains (Gliessman, 2007; Wezel et al., 2009; Altieri and Toledo, 2011). Agroecological farming systems therefore hold significant potential to enhance the sustainability performance of agriculture and agri-food value chains, aligning closely with the objectives of the EU 'Farm to Fork' strategy (Kerr et al., 2021; Vikas and Ranjan, 2024). Compared to mostly industrialized conventional agricultural production, agroecology brings greater complexity to farming systems. Digital technologies and smart agricultural equipment can play a key role in improving the performance of agroecological approaches at farm and landscape levels as well as by providing tools such as decision support systems that optimize soil and water management, pest control, and resource efficiency (Petraki et al., 2025).

These technologies, including artificial intelligence, geographic information systems, advanced imaging techniques, robotics, and sensors, are already available and applicable across most forms of farming. However, agroecological farming systems are likely to benefit more from digital solutions tailored to their specific needs and technology portfolios. Such tools enable continuous monitoring of practice transformations and performance through on-site data repositories, and support farmers' decision-making by integrating the various elements of agroecological systems into a holistic, systems-level framework (Ditzler and Driessen, 2022; Yang et al., 2023; Yépez-Ponce et al., 2023). The cost-effectiveness and performance of these solutions should be evaluated to ensure that they contribute not only to efficiency but also to the sustainability of agroecological systems and the quality of farm governance.

In this context, the agroecological transition needs to contribute to developing a roadmap for improving the productivity and sustainability performance of agroecological farming systems by assessing the availability of digital, data-driven solutions specifically tailored to agroecological farming. Furthermore, there is a need to evaluate the potential

for adapting existing 'standard' digital technologies used in agriculture to meet the specific requirements of agroecological approaches in farm and landscape management (Klerkx and Begemann, 2020; Bellon-Maurel et al., 2022). Special attention must be paid to data security aspects, interoperability, and the extent to which farmers and other stakeholders in the food supply chain accept and are able to use these solutions (Wolfert et al., 2017).

Despite the growing body of research on digital tools in livestock farming, limited empirical evidence exists on how digitalisation is perceived, adopted, and prioritised within pasture-based beef cattle systems, particularly from a multi-stakeholder perspective. To address this gap, the objective of this study is to identify the key drivers, barriers, trends, and risks associated with the digitalisation of Hungarian pasture-based beef cattle farming. By analysing insights from two participatory workshops, the study aims to provide practice-oriented knowledge that can support the development of future digital solutions tailored to agroecological livestock systems.

Digital technologies in cattle farming

As a response to the challenges of livestock production, Precision Livestock Farming (PLF) offers innovative solutions using digital technologies and automated systems that continuously monitor animal performance and welfare (Berckmans, 2017; Norton et al., 2019).

PLF technologies have been primarily adopted in intensive dairy production systems, where shorter distances within the farm simplify the collection of data from various devices. For example, robotic milking technologies offer significant labour savings and efficiency gains (Jacobs and Siegford, 2012). These automated systems continuously monitor milking processes in real time, boosting productivity while ensuring animal comfort throughout the procedure. Consequently, the technology not only rationalizes operational tasks but also improves animal welfare by reducing stress associated with traditional milking routines (Hopster et al., 2002).

Beyond robotic milking systems, a wide range of sensor-based solutions offer additional opportunities to monitor cattle health, providing farmers with useful information at both herd and individual levels without physical presence. These devices facilitate disease prediction, improve response times to health issues, and not only support individual animal welfare but also optimize herd management through better record-keeping and analysis (Sharma and Koundal, 2018; Neethirajan, 2023).

However, the implementation of these advanced technologies presents several challenges. Farmers may encounter barriers when adopting new technologies, including costs, lack of technical knowledge, and resistance to changing traditional practices. Studies have shown that while many farmers acknowledge the potential benefits, there remains considerable scepticism regarding the reliability and practicality of smart farming technologies. Therefore, education, subsidy, and practical training are essential to facilitate the transition towards smart cattle farming (Wolfert et al., 2017; Giagnocavo et al., 2025).

Digital technologies in beef cattle farming

In recent years, the demand for digital transformation has emerged among beef cattle farmers as well (Figure 1). Modern solutions offer significant advantages for both intensive production systems and pasture-based beef cattle farming, in response to challenges such as climate change, skilled labour shortages, and the growing need for production optimization. However, due to the differences between these two production systems, technology providers and equipment manufacturers must adapt their products to the specific

conditions of each system. The large physical size of pasture-based beef farms can pose challenges for data collection and transmission to centralized systems, and retrieving lost devices in open grazing areas can also be challenging. Furthermore, the different behavioural patterns of dairy and beef cattle may necessitate updates and modifications to data processing algorithms. Overcoming these challenges is essential for the implementation of modern, sustainable beef cattle production (Aquilani, 2022; Marchegiani, 2025).

Figure 1 Charolais beef cattle equipped with sensors on the pasture
Source: Own photo (2022)

Materials and Methods

As part of the PATH2DEA project, two participatory workshops were organized to identify the key drivers, barriers, trends, and risks associated with digitalisation in the Hungarian beef cattle sector, involving stakeholders such as farmers, advisors, researchers, and representatives of breeders' associations. Workshops were selected as the primary methodological approach because participatory formats are particularly effective for capturing stakeholder knowledge, practical experiences, and context-specific needs. In the context of digitalisation and agroecology, such methods allow farmers, advisors, and technology providers to jointly identify challenges, expectations, and system-level gaps that cannot be adequately revealed through questionnaires or individual interviews.

Workshop 1

The first workshop took place on 7 December 2023 at the Budapest office of the Institute of Agricultural Economics, with 16 participants: five farmers, two advisors, one breeders' association representative, three researchers, and five ÖMKi staff members.

The aim was to investigate how key stakeholders, primarily farmers and advisors, perceive the integration and use of digital tools within agroecological systems. Discussions centred on identifying the main drivers, challenges, risks, and priority areas associated with digitalisation in pasture-based beef cattle farming. The programme consisted of three structured activities, combining individual reflection with group-based visualisation and prioritisation.

The farmers participating in Workshop 1 represented a mix of small- and medium-scale pasture-based beef cattle operations from different parts of Hungary. The group included regenerative and agroecological family farms (e.g. Savory-inspired management with Angus and Carpathian Brown cattle), as well as conventional breeding-focused Charolais and Limousin herds. Farm sizes ranged from small family holdings to one large commercial enterprise managing more than 600 Limousin cattle across extensive grazing areas. Several farms used digital technologies such as Allflex MSD/SenseHub systems, while others relied on low-input or traditional management practices. This diversity ensured that early discussions captured a broad spectrum of practical realities, technological experiences, and production philosophies within the Hungarian beef cattle sector.

What does digitalisation mean to me?

Participants first reflected individually on what digitalisation meant to them, in both personal and professional contexts. Open-ended prompts and moderated discussion encouraged them to share associations, concerns, and aspirations. Key terms and concepts were collected on a shared board, creating a collective vocabulary that formed the basis for subsequent tasks.

What digital tools do I use, and for what purpose?

In a collaborative setting, participants co-created a large-scale mind map to visualise when, where, and for what purposes they use digital tools in daily life. Pre-defined thematic bubbles (e.g., Production, Info-communication, Household) were expanded with coloured post-it notes indicating specific tools, usage contexts, and device types (e.g., smartphone, computer). Moderators facilitated discussion on whether the tools served organisational, educational, or communicational functions, and how these related to agroecological principles.

Drivers and barriers, trends and risks of digitalisation

In the main session, stakeholders identified and discussed key drivers and barriers to adoption, emerging trends, and potential risks. Each thematic area was introduced with targeted prompts, followed by group discussion to ensure broad input. Responses were documented and prioritised through a collective ranking exercise, ensuring that all voices were incorporated into the final outputs.

Workshop 2

The second workshop was held on 22 October 2024 at the Horhos Valley Ecofarm (Tardona, Hungary) with 35 participants: fourteen farmers, three advisors, eight technology providers, four researchers, and six ÖMKi staff members. Given the large number of attendees, participants were divided into four smaller groups. All activities were conducted within these groups, and results are presented in aggregated form without distinguishing between individual group outputs.

The aim was to further investigate the opportunities and limitations of digitalisation in pasture-based beef cattle farming, with particular emphasis on agroecological principles. Three structured tasks were designed to capture practical experiences, identify gaps and missing functionalities in existing digital tools, and reflect on systemic shortcomings across the supply chain.

The farms represented in Workshop 2 covered a wide geographic range across Hungary, including Transdanubia, the Great Plain, and the foothills of the Bükk Mountains. Participants included mainly small- and medium-scale extensive beef producers, alongside several larger commercial operations. Both conventional and agroecological/organic farms were present, as well as holdings at different stages of agroecological transition. Farm sizes varied considerably, with the most common range between 11–100 ha, complemented by both smaller (< 10 ha) and substantially larger (> 500 ha) enterprises. Production systems included breeding herds (e.g. Charolais, Limousin, Hungarian Simmental, Angus, Carpathian Brown cattle) as well as commercial beef production systems. Digitalisation levels varied widely: some farms were equipped with advanced sensor-based monitoring tools, whereas others operated without any dedicated digital systems, relying instead on conventional, low-input management practices. This diversity ensured that the workshop discussions captured a wide spectrum of experiences, technological needs, and practical constraints across the Hungarian pasture-based beef cattle sector.

Gap analysis at field level

Focusing on the identification of missing or underperforming functionalities, this task examined digital tools used in beef cattle production. Participants reflected on their own farming experiences and discussed specific pain points in relation to digital support for production tasks. The emphasis was placed on functionalities (e.g., monitoring, alerting, documentation) rather than on specific tools or brands. Moderators facilitated the discussions using printed templates and post-it notes. Outputs from each group were collected and synthesised in a collective analysis.

Gap analysis across the supply chain

This task involved mapping supply chains and identifying opportunities and gaps for digitalisation across the different stages, from on-farm production to product sales. A printed template provided the framework for group-level mapping, supported by guiding prompts from the facilitation team. Discussions examined how digital tools are (or could be) used to enhance traceability, logistics, documentation, and transparency. Each group presented its map, followed by a joint discussion on key barriers and future needs.

Card sorting exercise

In the final activity, participants explored how digitalisation can support agroecological farming systems. Each group received a set of 27 statements and was asked to sort them on a grid according to the strength of agreement or disagreement they felt toward each statement. The exercise was based on a pre-defined set of assumptions, including affordability, user-friendliness, and contextual applicability of digital tools. Groups were encouraged to reach consensus through discussion, and both sorting outcomes and key discussion points were recorded for subsequent analysis.

All activities were facilitated by the research team and supported with printed materials and facilitation guides developed within the PATH2DEA project. The workshop format

was intended to elicit practical insights from stakeholders across the value chain, ensuring balanced representation and active interaction within the mixed-actor groups.

Results and discussion

Workshop 1

What does digitalisation mean to me?

In this section, we first briefly introduced the concept of digitalisation and its relevance to the agricultural sector. Subsequently, participants were invited to reflect on what digitalisation means to them in both personal and professional contexts. Through a structured brainstorming session, the following key concepts emerged, illustrating participants' perceptions of digital technologies and their potential impact:

Fast transfer, aggregation and easy access to information; Increasing efficiency; Data storage; Interoperability; Scale dependency; Decision support and preparation; Controlling; Information sharing; Tracking; Transparency; System; Quantification; Planning; Data analysis; Sensors and cameras; Workforce optimisation; Automation; Real-time monitoring.

These terms represent a broad yet coherent understanding of digitalisation as a transformative force, with particular emphasis on data-driven decision-making, system transparency, and the optimisation of both inputs and outputs in agricultural processes.

What digital tools do I use, and for what purpose?

In the second phase of the workshop, participants were invited to reflect on how digital technologies are integrated into their daily routines. They were asked to mentally walk through a typical day and identify moments and contexts in which they interact with digital tools, in both professional and personal settings.

Through this reflective exercise, a structured mind map was generated, highlighting key domains where digitalisation plays a role (Figure 2). Major thematic areas identified included Production, Info-communications, Mobility and Transport, Sports, and Household, within which specific tools and technologies were listed. Each main category was further subdivided into subdomains reflecting particular functionalities.

This visualisation illustrates the wide spectrum of digital engagement, ranging from highly specialised agricultural applications to general-purpose tools for communication, learning, and household management. The exercise revealed not only the diversity of digital tool usage but also the layered and interconnected nature of their application. For many participants, the boundary between professional and personal digital tool use proved to be fluid, reflecting the increasing ubiquity of digitalisation in all spheres of life.

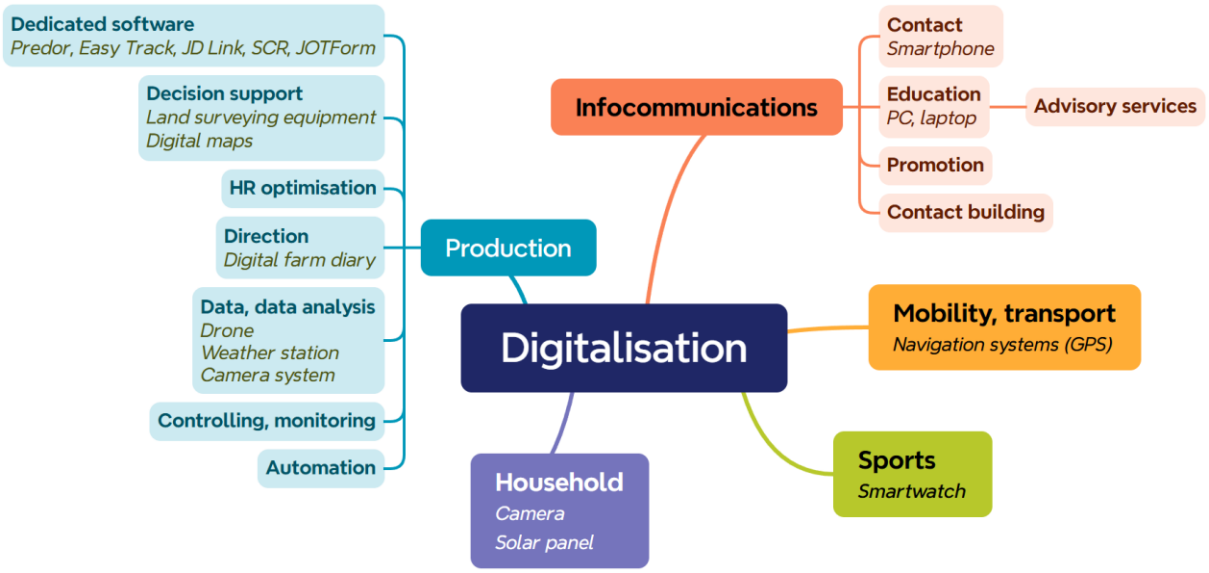

Figure 2 Participant-generated mind map illustrating digital tools and their purposes across different domains

Drivers and barriers, trends and risks of digitalisation

One of the key objectives of the first workshop was to explore the diffusion of digital technologies among farmers, including both adopted and non-adopted tools. Participants were asked to identify the main drivers, barriers, trends, and risks related to digitalisation in their agricultural practice. These elements were subsequently prioritised through a collective ranking exercise.

Drivers

Farmers identified the following as key motivations for adopting digital technologies in the context of pasture-based beef cattle farming:

- they see all the data at the same time - transparency
- decision support
- traceability
- reduction in human resources
- efficiency, monitoring (territory, animal, pasture) - controlling, observation
- commitment to adopting technology and belief in its benefits
- reliability, credibility
- profitability
- presentability to external actors (e.g. veterinarian)
- professional confirmation
- rapid information flow
- mentoring, educational programmes
- remote access, comfort

Among the listed factors, *they see all the data at the same time – transparency* and *efficiency, monitoring (territory, animal, pasture) – controlling, observation* were originally mentioned as separate elements. However, participants later agreed that each pair

represents a closely interlinked concept. Consensus emerged regarding the most important drivers of digital adoption: *transparency* through simultaneous access to all data, and *efficiency* combined with *monitoring and control* were ranked as the top motivators. In addition, *commitment to adopting technology and belief in its benefits* and *profitability* were also identified as key driving forces.

Barriers

The complete set of barriers identified by participants included the following:

- vulnerability (e.g. to manufacturers, technicians)
- possibility of inaccuracy (e.g. weight estimation)
- difficulty of access (e.g. mobile network coverage)
- infrastructural difficulties
- lack of adaptability to grazing conditions
- price and maintenance costs
- lack of knowledge
- lack of confidence in quality
- data protection
- time: the novelty wears off, usage decreases
- demand and supply do not meet

Vulnerability emerged as the most significant barrier, especially in terms of dependency on manufacturers or external service technicians. This was followed by *difficulty of access*, often linked to limited mobile network coverage in rural areas, and *price and maintenance costs*, which were also widely acknowledged as critical constraints. These findings highlight that beyond technical and infrastructural issues, psychological and market-related factors also play a considerable role in shaping attitudes toward digitalisation.

Trends

Participants also identified areas in which they would like to further expand their use of digital technologies soon. Their responses reflect a forward-looking and exploratory mindset, with interest in both hardware and software innovations that could improve operational efficiency and animal welfare. The following areas were highlighted:

- drone technologies: for data collection, machine replacement, pasture monitoring
- common platform for collected data (integration)
- virtual fence
- tools for animal monitoring (e.g. calving monitoring)

The *common platform for collected data* and the *virtual fence* were particularly emphasised. The former reflects a growing demand for system-level integration and interoperability, while the latter directly addresses the challenges of pasture-based cattle farming, offering potential improvements in flexibility, efficiency, and animal control without physical infrastructure. These responses suggest a strong interest for technologies supporting automation, data centralisation, and remote monitoring, particularly in relation to pasture and animal management.

Risks

While participants were generally open to further integrating digital technologies, they also acknowledged several inherent risks. These reflect both technical uncertainties and behavioural tendencies that could undermine long-term adoption. The main risks identified were:

- data security
- inaccuracy
- wrong data
- getting too comfortable
- maintenance
- reliability
- price sensitivity

Among these, *maintenance* and *reliability* were emphasised as the most critical concerns. Maintenance refers to the need for ongoing technical support, servicing, and potential downtime, while reliability reflects uncertainty about consistent device performance under field conditions. These risks are particularly relevant in extensive, pasture-based systems, where equipment may be exposed to harsh environments and where immediate technical assistance is often unavailable.

Workshop 2

Gap analysis on field level

During this task, participants identified several key functional gaps in the digital tools currently available for beef cattle management. A recurring theme was the absence or unreliable performance of functions such as individual animal alerting in emergency situations (e.g. calving, injury, loss), detection of heat stress, and monitoring of suckling behaviour in newborn calves. Although some of these features are included in the official product specifications of commercially available systems, they often prove to be ineffective or generate excessive false alarms in practical settings. These shortcomings were attributed, at least in part, to the lack of technologies specifically tailored to the needs of extensive beef cattle production.

Beyond sensor functionalities, farmers highlighted the excessive administrative burden they face as a fundamental issue. In this context, they emphasised the potential value of improved system interoperability in easing these bureaucratic challenges. Suggestions included leveraging RFID-based animal identification in conjunction with other digital platforms, improving data integration, and embedding barcode or QR code scanning functionalities into herd management applications. Such enhancements could simplify the process of recording veterinary treatments and linking them directly to individual animal records within the digital systems.

The discussions also revealed a range of perspectives and expectations regarding digital tool development. As one participant noted, “Tools that know a lot are expensive, financial support can help to purchase them.” Another remarked, “RFID technology is cheap. It should spread faster.” Several participants emphasized the importance of system integration and data portability: “It would be nice if these could finally work as a unified site/farm management system.”

These insights reflect both the practical needs and the aspirational directions for the future development of digital technologies in beef production systems, highlighting that effective solutions must combine technical reliability, system integration, and financial accessibility.

Gap analysis across the supply chain

In the Hungarian context, supply chains in the beef cattle sector are typically short. Farmers either sell live animals to local or foreign buyers or process beef products themselves and sell them directly to restaurants or consumers. The mapping exercise (see Figure 3) illustrated these simplified chains and revealed the limited digitalisation currently in place.

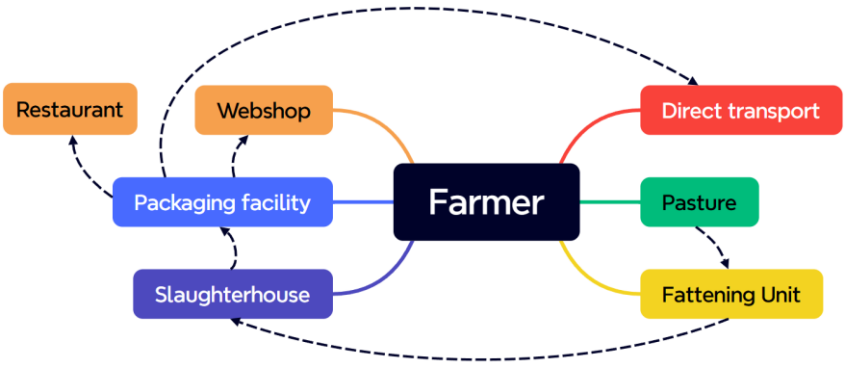

Figure 3. Example of a short supply chain of pasture-based beef cattle farming in Hungary

Participants described these short supply chains as both a practical reality and a persistent source of administrative burden. As one participant noted, "In our country these supply chains are short. However, administration is difficult." Others echoed that "the follow-up in the supply chain is still paper based," and that "many papers are still required officially for sale and transportation."

According to the discussion, official administrative processes, including animal traceability and health documentation, are still largely paper-based or handled by veterinarians through the Hungarian Unified Registration and Identification System. The integration of digital tools into these supply chains is hindered by the overall underdevelopment of the digital administration systems. Most of the currently used technologies, such as sensors for monitoring animal development, digital scales for measuring weight, and digital tools for managing sales, support only individual production tasks and are not integrated into broader supply chain functionalities.

Participants also emphasised the absence of digital tools to support logistics, streamline documentation, or enable value-added traceability. On breeding farms, for example, DNA sampling and microchipping for animals with high genetic value were mentioned as desirable but largely unavailable. By contrast, beef product traceability at the slaughterhouse level was considered more advanced and digitalised.

Card sorting exercise

The sorting exercise revealed diverse views among stakeholders on how digital tools can support agroecological farming. Although each group ranked the statements differently,

several cross-cutting trends emerged. Statements highlighting the role of digital tools in improving decision-making through data access and analytics received the highest agreement. Tools that enhanced coordination and saved time in daily tasks were also widely appreciated. These results indicate a shared recognition of the informational and organisational benefits of digitalisation.

At the same time, the least agreement was found for statements related to diversification of farm activities (e.g. incorporating new crops, livestock or services), ease of maintenance and repair, transparent data use, and marketing support. Notably, one group considered marketing highly important, while others placed it low, showing that stakeholder priorities depend heavily on context, such as farm type and market access.

The discussions also revealed distinct differences between stakeholder types. A technology provider, for example, noted: "Energetical efficiency of the tools is important." A farmer, however, countered: "Energetical efficiency is not so important." Advisors raised questions like: "How to get farmers interested in agroecological practices?"

These findings align with previous research showing that while PLF technologies can enhance decision-making, monitoring and animal welfare, their adoption in extensive grazing systems remains constrained by infrastructural, economic and organisational factors (Berckmans, 2017; Norton et al., 2019; Wolfert et al., 2017). Similarly, the limited spread of digital tools in agroecological farming reflects well-documented challenges such as the need for context-specific solutions, farmer-centred design, and interoperable, low-maintenance systems (Gliessman, 2007; Wezel et al., 2009; Klerkx & Begemann, 2020; Bellon-Maurel et al., 2022). Our results therefore confirm international trends, but also reveal Hungary-specific constraints—most notably administrative burdens and insufficient rural connectivity—that further restrict the practical integration of digital tools in pasture-based systems.

This study is based on qualitative insights from two participatory workshops, which—while valuable for capturing diverse stakeholder perspectives—do not allow for statistical generalisation. The number of participating farms, although regionally diverse, does not represent the full structural variability of the Hungarian beef cattle sector. Furthermore, workshop dynamics may introduce self-selection bias, as farmers with stronger interest in innovation might be overrepresented. These limitations should be considered when interpreting the findings.

Despite recognising clear benefits, farmers emphasised that digitalisation remains limited because current tools are not sufficiently adapted to extensive grazing conditions, rural connectivity is often inadequate, and the cost–maintenance ratio is perceived as unfavourable. These practical constraints, combined with administrative burdens and low system interoperability, reduce farmers' willingness to invest in digital solutions.

Conclusions

This study identified both significant opportunities and persistent challenges related to the digitalisation of pasture-based beef cattle farming in Hungary. Farmers and stakeholders highlighted benefits of digital solutions such as increased transparency, decision support, and the promise of improved animal welfare, while also noting barriers including technical limitations, high maintenance costs, and the lack of integrated digital solutions across the supply chain. The workshops revealed an urgent need for more reliable and

context-specific sensor technologies, particularly for calving prediction and animal monitoring, as well as greater interoperability and user-friendly platforms to ease administrative burdens. Perspectives varied widely among stakeholders, especially regarding marketing, maintenance, and energy efficiency, which underscores the necessity for adaptable digital tools tailored to diverse agroecological contexts.

The main findings from all workshops are summarised in Table 1, providing a concise overview for future research and policy development.

Table 1. Summary of main findings from Workshop 1 (WS1) and Workshop 2 (WS2)

Topic	Key Points / Findings
WS1 – Digital tool usage mapping	Wide range of tools used across production, info-communications, mobility & transport, sports, and household; strong overlap between professional and personal use.
WS1 – Drivers	Transparency (seeing all data at once), decision support, traceability, efficiency & monitoring, control and observation, commitment to adopting technology and belief in its benefits, reliability, profitability, presentability, rapid information flow, mentoring, remote access.
WS1 – Barriers	Vulnerability to manufacturers/technicians, inaccuracy, lack of access (mobile coverage), infrastructural limits, lack of adaptability to grazing conditions, price/maintenance costs, lack of knowledge/confidence, data protection, novelty loss, mismatch of demand & supply.
WS1 – Trends	Interest in drones, integrated data platforms, virtual fences, animal monitoring tools (e.g. calving).
WS1 – Risks	Data security, inaccuracy, wrong data, getting too comfortable, maintenance, reliability, price sensitivity.
WS2 – Gap analysis (field level)	Missing/ineffective functions: individual alerts (calving, injury, loss), heat stress detection, suckling monitoring; excessive false alarms; lack of adaptation to extensive beef systems. Heavy administrative burden, low interoperability; RFID potential; QR/barcode suggestions.
WS2 – Gap analysis (supply chain)	Supply chains are short; administration is still paper-based; digitalisation mainly at slaughterhouse stage; no integrated logistics/documentation/traceability tools; DNA sampling & microchipping desirable.
WS2 – Card sorting	Diverse stakeholder views; highest agreement on decision-making support, coordination, time saving; lowest on diversification of farm activities, ease of maintenance, transparent data use, marketing. Context affects priorities (farm type, market access).

Based on these findings, farmers could benefit from interoperable, low-maintenance digital tools tailored to extensive pasture-based systems, while technology developers should prioritise reliability, connectivity-independent functionalities and user-centred design. Strengthening advisory support and simplifying administrative processes may also accelerate digital adoption in the sector.

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