A Framework Integrating Agile Software Development Principles for Co-Design and Participatory Cost-Benefit Evaluation in Digital Agriculture

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Abstract—**Digital innovation in agriculture often struggles to meet real operational needs due to limited stakeholder involvement and insufficient assessment of context-specific costs and benefits. To bridge this gap this paper introduces AGILE-CBA, a methodological framework that (a) integrates co-design practices, (b) is structured through a Scrum Agile development process, and (c) includes a participatory cost-benefit evaluation. The framework organises co-design into a seven-step iterative cycle, embedding a five-step participatory assessment loop within each sprint. This dual structure enables the continuous and situated evaluation of both expected and observed costs and benefits, encompassing tangible and intangible aspects. By aligning key Scrum practices, such as backlog management, sprint reviews and retrospectives, with facilitated dialogue and collective reflection, AGILE-CBA can support more informed prioritisation, enhances context relevance, and reduces adoption risks. Facilitators play a crucial role in mediating communication and adjusting the pace and content of participatory activities to seasonal workloads and user capabilities. The approach is particularly suited to farming systems characterised by variability, environmental and seasonal dependency, and multi-actor complexity, offering a flexible and replicable pathway toward more inclusive, context-aware, and sustainable digital agriculture.**

Keywords—Digital Agriculture; Agile Software Development; Scrum; Technology Co-design; Participatory Evaluation; Cost-Benefit Analysis.

I. Introduction

The growing diffusion of digital technologies is profoundly transforming production, management and decision-making processes within agri-food systems. IoT devices, advanced sensors, management platforms, predictive models, traceability tools, and artificial intelligence applications have become central components in contemporary innovation strategies. Digital architectures enable data-driven models [1], while precision farming technologies contribute to reducing input use and environmental impacts [2]. Simultaneously, the introduction of new digital infrastructures is reshaping organisational logics and on-farm decision-making practices [3].

However, the actual adoption of digital technologies by agricultural actors remains uneven. Beyond structural and institutional constraints, barriers related to limited digital skills, risk perception and trust in providers represent critical issues [4][5]. These are compounded by the implicit costs of transition, such as investments in learning, adjustments in daily practices, tensions between automation and human control [6], and emerging forms of technological dependency that may undermine decision-making autonomy [7].

One of the key challenges lies in the timely and context-specific assessment of the costs and benefits associated with digitalisation processes. *Ex ante* evaluations are often based on abstract or generic projections, while *ex post* assessments tend to occur when opportunities for corrective action are limited. Such approaches are poorly suited to capturing the situated, negotiated and dynamic nature of technology adoption pathways [8], particularly in agriculture, where linear models, such as the waterfall paradigm, exhibit limited adaptive capacity [9].

In light of these limitations, this paper proposes a methodological framework for tailoring an Agile development process, i.e., Scrum – originally developed in software engineering – to supports both co-design and participatory cost-benefit analysis (CBA). Scrum development is based on short iterations, continuous feedback, and incremental value generation [10][11], and is here reinterpreted as a means to enhance the adaptability of technological solutions within agricultural systems.

The paper is structured as follows. Section II introduces the theoretical foundations of Agile and its adaptation to agricultural contexts. Section III examines the costs and benefits of agricultural digitalisation, while Section IV discusses participatory design and co-development practices. Section V analyses the integration of Agile with digital agriculture, identifying both opportunities and methodological challenges. Section VI presents the proposed AGILE-CBA iterative framework, detailing its operational structure, embedded evaluation activities and convergence mechanisms. Finally, Section VII discusses the implications, limitations and future directions of the proposed approach.

II. The Agile approach in agricultural contexts

Originally developed in response to the limitations of the waterfall paradigm, Agile introduces a flexible, iterative, and user-centred methodology [12]. The *Manifesto for Agile Software Development* outlines four fundamental principles: valuing individuals and interactions over processes and tools, prioritising working solutions over comprehensive documentation, fostering continuous collaboration with users and embracing change [10]. These principles are operationalised through practices such as cyclic sprints, dynamic reprioritisation, shared management of the product backlog, and structured feedback mechanisms [13], which are the fundamental building block of Scrum, a specific Agile method, considered as the reference for this work.

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Although the application of Agile methods in general, and Scrum in particular, to agriculture remains relatively unexplored, it appears particularly promising. Agricultural systems are marked by heterogeneous needs, high operational variability, and the presence of tacit, non-formalised local knowledge [14]. In such settings, linear approaches risk producing decontextualised solutions that are difficult to adopt and rapidly become obsolete [15]. Scrum, by contrast, supports context-sensitive innovation that responds to emerging constraints, operational requirements and users' values [6].

Moreover, the approach aligns with the principles of Responsible Research and Innovation, promoting transparency, openness, mutual accountability, and continuous adaptation [16]. Value is generated through collective negotiation among actors, rather than imposed external standards, making Scrum particularly suitable for agricultural contexts, where technology interacts with material labour, local knowledge, and productive identities [17].

Agricultural systems differ significantly from industrial or service sectors because they are closely connected to natural cycles, weather and the ongoing climate crisis, and the diverse characteristics of agricultural landscapes. Production processes are deeply embedded in material environments shaped by living organisms and constrained by seasonality and environmental uncertainty. Agricultural work also relies heavily on practical experience and context-specific knowledge, which are difficult to translate into standardised procedures or software requirements. These characteristics make the agricultural sector particularly sensitive to methodological rigidity and highlight the need for adaptive approaches that are able to balance technical design with practices based on actual working conditions.

III. Costs and benefits of agricultural digitalisation

The introduction of digital technologies in agriculture is profoundly transforming both technical and productive processes as well as farm management practices. While new opportunities are emerging in terms of efficiency and sustainability, implicit costs, adoption barriers, and risks of exclusion are also becoming evident.

In the crop sector, the combination of automated guidance, variable rate mapping and sensor-based monitoring has led to substantial reductions in the use of fertilisers and pesticides, alongside significant yield increases [18], highlighting notable gains in productivity and efficiency.

In livestock farming, automation of milking and feeding, health monitoring, and predictive management have reduced waste, improved energy efficiency, and limited the use of antibiotics through earlier diagnosis [19].

Beyond productive benefits, digitalisation entails a broader organisational restructuring. A living lab conducted in Italian agro-pastoral farms identified three main cost categories: transition costs (training), transaction costs (information management and interoperability), and operational costs (maintenance and updates). Reported benefits included improved work satisfaction, increased attractiveness for younger generations, more effective traceability, and enhanced product valorisation [20].

In other contexts as well, digital solutions have increased profit margins and reduced labour requirements, positively impacting the organisation of agricultural work [21].

However, these benefits coexist with structural constraints, including high initial investment costs, limited digital literacy, fragmentation of available tools, and integration challenges. Concerns regarding data governance – particularly the risk of losing control and becoming dependent on technology providers – further contribute to farmers' reluctance [22][23].

Agricultural digitalisation thus emerges as an ambivalent process: it offers opportunities for enhanced sustainability and productivity, but requires situated and participatory evaluation to prevent exclusionary effects.

IV. Participation and co-design in technological development

The success of digital technologies depends on their ability to adapt to real-world contexts through participatory innovation processes. A lack of alignment with operational conditions, and user expectations constitutes a key barrier to adoption [24]. Solutions developed without local involvement often prove inadequate or are rejected altogether [8].

Co-design promotes continuous interaction between developers and users through workshops, prototyping and interviews, fostering the emergence of shared solutions [25]. This approach has been demonstrated to enhance the usability of diagnostic tools [26], increase technological trust [23], and foster a stronger sense of ownership among stakeholders.

Living labs represent a significant evolution in this regard: experimental environments operating under real conditions that enable iterative co-development among diverse actors [27][28]. Their effectiveness depends in part on the maturity level of the innovation being deployed [31]. In Italian agro-pastoral contexts, the co-design of a farm information system generated solutions tailored to real needs and indirect benefits such as increased digital skills and greater transparency in data management [20].

Participatory approaches can help reduce inequalities, but require systematic engagement from the earliest stages [22]. It is essential to adopt reflexive practices to anticipate the social and cultural implications of digital innovations [24]. While the diversity of existing models complicates generalisation, adaptive frameworks are emerging that seek to integrate co-design, iteration and ongoing evaluation [31].

V. Integrating Agile with digital agriculture: opportunities and challenges

The increasing complexity of digital agricultural systems has stimulated growing interest in the Agile approach as a flexible methodological infrastructure. Recent studies have explored its adaptation to farm management, with encouraging results in terms of coordination, efficiency and communication [30][33]. The use of typical Scrum tools – such as backlogs, sprint planning, and meetings – has improved decision-making processes even in non-digital contexts, provided that a prior phase of contextualisation is conducted.

The integration of Agile with advanced technologies (AI, IoT, automation) enables real-time optimisation of agronomic activities and enhances adaptive capacity [30]. Nevertheless, significant methodological challenges arise: translating concepts such as "user story" into agricultural language, adapting to seasonal cycles and ensuring adequate facilitation [30].

Overall, Agile offers a strategic opportunity for fostering a more responsive, collaborative, and continuously learning-oriented agricultural sector [33]. To fully exploit this potential it is important to develop an operational framework that integrates co-design, iteration and participatory evaluation in a manner consistent with the specificities of the agricultural domain.

VI. Towards an Iterative Framework for Co-Design and Participatory Evaluation

The previous sections have highlighted three key aspects: the transformative potential of agricultural digitalisation, the importance of participatory and adaptive approaches, and the lack of tools capable of iteratively integrating design and evaluation. Scrum provides a useful basis for structuring short development cycles characterised by continuous feedback and flexible decision-making. However, in practice, the assessment of technological impacts is still rarely integrated into the design process. In agricultural innovation, impact assessment activities have traditionally been based on *ex post* evaluations, which limit opportunities for learning and adaptation during implementation [32]. Furthermore, many assessment frameworks remain poorly contextualised to the specific socio-technical and environmental conditions of local agricultural systems resulting in a weak link between assessment results and design decisions [33]. Therefore, research in digital agriculture requires participatory and forward-looking approaches that explicitly integrate evaluation into iterative design cycles and thus enable continuous learning and local adaptation [34].

This contribution proposes a framework that integrates Scrum Agile principles with a participatory cost-benefit evaluation. The aim is to actively involve agricultural actors not only in the co-design of digital solutions, but also in the progressive assessment of the advantages and disadvantages that emerge during implementation, thereby making these results an integral part of the design decisions.

The following sections outlines the operational structure of the proposed framework and the modalities for adapting it to the agricultural context. For clarity, we label the iterative phases (A.1–A.7) and the embedded evaluation activities (B.1–B.5) with concise descriptive headings adapted from Scrum and participatory evaluation practice; these labels are proposed for readability and are not intended as a formal taxonomy.

A. Operational structure of the AGILE-CBA iterative cycle

The AGILE-CBA cycle represents the integration of iterative development – following the Scrum framework – with participatory cost-benefit evaluation. Its methodological logic is based on a cyclic sequence of seven distinct phases, each involving technical, evaluative and participatory activities. The coherence between incremental development (Scrum) and evaluative knowledge generation (CBA) is ensured through the systematic integration of design and reflexive activities throughout the cycle.

Step A.1. **Value Framing**

Participatory definition of value and evaluation criteria

This phase corresponds to *Sprint 0* in Scrum, where the product vision and overarching objectives are defined. Within AGILE-CBA, stakeholders engage in collaborative activities (e.g., interviews, workshops) to articulate needs and expectations related to digitalisation. A shared framework of value criteria and relevant impact dimensions is co-constructed, serving as the reference for evaluation. Expected costs and benefits – both tangible (e.g., economic savings, productivity gains) and intangible (e.g., learning time, quality of life) – are identified, along with indicators to be monitored.

Step A.2. **Backlog Planning**

Sprint planning and construction of the evaluative backlog

This phase corresponds to *Sprint Planning*, where development priorities and objectives are jointly defined. Within AGILE-CBA the traditional Product Backlog is expanded to include an Evaluative Backlog, linking each user story to a dedicated CBA sheet. These sheets specify expected benefits, estimated costs (economic, organisational and cognitive), relevant indicators and priority levels. Participatory tools are used to support collective prioritisation, ensuring that selected features reflect the highest perceived net value among stakeholders.

Step A.3. **Co-Design Sprint**

Technical development and incremental co-design

This phase corresponds to the sprint's development stage, during which the technical team (developers, agronomists and designers) delivers a functional increment following standard Scrum practices such as daily meetings, task boards and backlog refinement. Within AGILE-CBA, technical work is tightly integrated with continuous interaction with stakeholders through a combination of structured and informal exchanges. Each sprint includes joint review sessions and on-farm testing moments where farmers, technicians, and developers discuss the functionalities under development. In parallel, digital communication channels – such as shared dashboards, messaging platforms, and collaborative documents – enable real-time feedback between meetings. This dual mode of interaction ensures that design decisions remain continuously informed by user experience and operational constraints allowing early identification of usability issues and the co-creation of practical adjustments within each iteration.

Step A.4. **Field Validation**

Field testing and collection of qualitative and quantitative evidence

This phase corresponds to the *Sprint Review* and serves as a checkpoint for the developed increment. Testing is carried out under real operational conditions – on farms, in the field, or within livestock facilities – and combines multiple data collection methods, including digital logs, semi-quantitative assessments, interviews, observation sheets and user narratives. The aim is to obtain empirical evidence on usability, usefulness, operational performance, and encountered challenges, providing a factual basis for subsequent evaluative reflection.

Step A.5. **Collective Reflection**

Participatory analysis of observed costs and benefits

This phase extends the *Sprint Retrospective* to include a comprehensive evaluative component. The evidence collected during testing is jointly discussed for each developed feature, assessing generated value, incurred costs, user satisfaction and any observed trade-offs. The corresponding CBA sheets are updated *ex post* and compared with initial expectations allowing deviations and emerging insights to be documented. Visual tools are employed to facilitate collective reflection and support the negotiation of shared interpretations of results.

Step A.6. **Decision Round**

Shared decision: scale, modify or discard

At this stage, a shared decision is taken on the continuation of each evaluated feature. Based on retrospective insights, the team determines whether a component should be scaled (integrated permanently into the system), modified to address identified issues (if adjustments are needed), or discarded (if costs outweigh benefits or utility is marginal). These decisions, grounded in empirical evidence and collective judgement, are documented in the backlog and guide the planning of the next sprint.

STEP A.7. **Value Communication**

Visualisation and communication of the generated value

This final phase corresponding to the *product increment delivery*, focuses on synthesising and communicating the outcomes of the completed cycle. Technical and evaluative data are integrated into concise summary reports or visual dashboards, designed to be understandable even for non-expert audiences. The emphasis is placed on the functionalities developed, the value generated, the resources employed and the decisions informing the next sprint. Communication targets both internal stakeholders and external actors, including funders, public institutions, and agricultural networks.

B. Participatory evaluation embedded in Scrum sprints

Within the AGILE-CBA framework, participatory cost-benefit evaluation is not positioned as a separate or terminal activity, but is fully embedded in the iterative structure of Scrum. In each cycle (sprint), evaluation activities follow a well-defined articulation composed of five interconnected steps, designed to strengthen the link between technical development and the assessment of generated value.

STEP B.1. **Elicitation**

Participatory elicitation of expected costs and benefits

This step involves direct engagement with stakeholders typically during sprint reviews and retrospectives, to elicit qualitative and contextual perceptions of the costs and benefits associated with each developed functionality. Participants are encouraged to describe their experiences in concrete terms identifying both tangible aspects – such as operating time, economic savings, or avoided errors – and intangible ones, including clarity, sense of control and adaptability. These insights form the basis for subsequent analysis and refinement within the iterative evaluation process.

STEP B.2. **Evidence Analysis**

Analysis and elaboration of collected evidence

This step entails the structured analysis and synthesis of the evidence collected throughout the sprint. Qualitative data – obtained from observations, interviews, and visual tools such as canvases, grids, and maps – are consolidated into dedicated evaluation sheets linked to each user story. These sheets document the actual costs incurred, the benefits observed, any issues encountered and the corresponding levels of user satisfaction, providing a consistent basis for comparison across successive iterations.

STEP B.3. **Validation Dialogue**

Visual restitution and collective validation

This step focuses on the collective validation of the analysed results. The findings are visually presented and discussed with the stakeholder group, using simplified and accessible tools that encourage participation. Through facilitated dialogue, the team guides a shared reflection on the actual value-generating capacity of the developed solutions and on their observed implications within real use contexts.

STEP B.4. **Redefinition**

Redefinition of design priorities

This step focuses on the adjustment of design priorities based on evaluative evidence. The findings emerging from participatory assessment are combined with technical criteria such as effort and feasibility to guide the backlog update. In this way, decisions about which features to develop, improve, or discard are systematically informed by user feedback rather than being driven solely by technical considerations.

STEP B.5. **Learning Consolidation**

Consolidation and communication of cumulative learning

This final step promotes the consolidation of learning through the synthesis of evaluation outputs accumulated across multiple sprints. Conducted periodically (such as every few cycles) it allows the identification of recurring patterns, emerging trends and transferable insights. The resulting synthesis supports both adaptive decision-making within the project and the broader communication of knowledge gained throughout the iterative process.

The participatory evaluation loop thus functions as a transversal cognitive engine that accompanies the entire co-design process, reinforcing the adaptability, inclusiveness and long-term relevance of the digital solutions developed within agricultural contexts.

C. Iterative convergence of design and evaluation processes

The participatory CBA activities described above (section VI.B) are not carried out as a separate analytical module, but are fully embedded within the seven operational phases of the AGILE-CBA framework (section VI.A). Each evaluation step corresponds to specific moments of the iterative cycle, ensuring that cost-benefit reflection progresses in parallel with technical development and user interaction.

In particular, Elicitation (B.1) occurs primarily during Step A.1. (*Participatory definition of value and evaluation criteria*), where stakeholders collaboratively define value dimensions, expected benefits, and relevant indicators. Early forms of elicitation also reappear in Step A.2. (*Sprint planning and construction of the evaluative backlog*), as participants refine and prioritise user stories according to perceived value and feasibility.

Continuous feedback collected during Step A.3. (*Technical development and incremental co-design*) contributes directly to both the elicitation and analysis stages of the CBA loop. In this phase, in-process observations and user inputs are recorded within the evaluative sheets, ensuring that reflection on value evolves in parallel with technical implementation and the adjustments made by the development team.

Evidence Analysis (B.2) takes place mainly in Step A.4. (*Field testing and collection of qualitative and quantitative evidence*), when empirical data and user feedback are gathered under real operational conditions, and continues through Step A.5. (*Participatory analysis of observed costs and benefits*), where this material is collectively interpreted and translated into updated evaluation sheets.

The Validation Dialogue (B.3) stage is directly associated with Step A.5. as well, expanding the retrospective moment to include deliberative discussion on the results and their implications. The subsequent Redefinition of design priorities (B.4) is operationalised in Step A.6. (*Shared decision: scale, modify or discard*), when the team decides how to act upon the findings, linking evaluative insights to design decisions.

Finally, Learning Consolidation (B.5) is integrated into Step A.7. (*Visualisation and communication of the generated value*), where the synthesis of evaluative evidence across multiple iterations supports collective learning and knowledge accumulation for both participants and designers.

Through this mapping AGILE-CBA ensures that participatory evaluation is not a static or terminal process but a dynamic and continuous component of co-design, feeding each development cycle with updated insights on value, usability and feasibility. Figure 1 illustrates how the five participatory CBA activities are integrated within the seven phases of the iterative AGILE-CBA cycle.

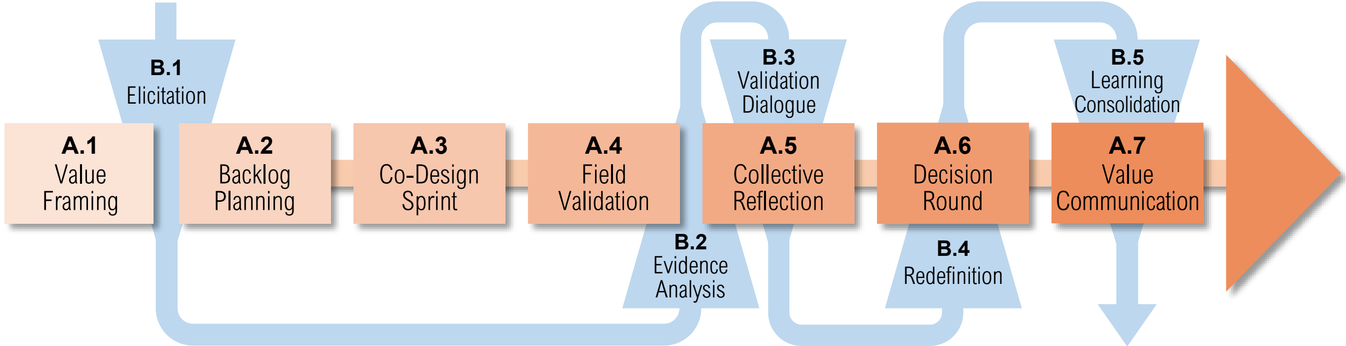

Figure 1. The AGILE-CBA framework integrates iterative development (A.1–A.7) with participatory cost–benefit evaluation (B.1–B.5). The seven phases depict the co-design process, while the five embedded steps enable continuous stakeholder feedback and value reflection.

VII. Discussion and Conclusion

This paper has presented the AGILE-CBA framework as a methodological response to the challenges of designing and evaluating digital technologies in agriculture. By integrating iterative development using a Scrum-based approach with participatory cost-benefit assessment, the framework addresses two major gaps identified in the literature: the disconnection between design and evaluation, and the need for adaptive and context-sensitive innovation models.

The AGILE-CBA framework responds to the persistent separation between technological design and impact assessment. The conventional assessments are often based on linear, *ex post* analyses that overlook the evolutionary and context-dependent nature of agricultural innovation [8][9][31][33][34]. AGILE-CBA integrates assessment into short iterative cycles, promoting adaptive learning and the progressive refinement of technical and organisational configurations. By combining Agile principles – short iterations, user-centred design and continuous feedback [10]–[13][30][31] – with participatory cost-benefit evaluation [20], it links technical performance with social value generation, grounding innovation in users' lived experiences.

The framework aligns with the literature on participatory and responsible innovation. Empirical evidence shows that digitalisation is most effective when users are involved throughout the development process, helping to define meanings, expectations and value [24]–[26]. Research on living labs confirms that real-world experimentation improves usability and contextual adaptation [27][28], but such environments often lack structured and iterative evaluation mechanisms. AGILE-CBA addresses this by formalising participatory reflection within each sprint and by using CBA sheets to record expected and observed costs and benefits. This strengthens transparency and reflexivity – key principles of Responsible Research and Innovation [16][17] – transforming evaluation from a terminal audit into a continuous, deliberative process that informs design decisions.

To ensure relevance in the agricultural sector, the Scrum framework must be adapted to these organisational and temporal realities. The assignment of roles – such as Product Owner and team members – can be modified to include trusted intermediaries such as cooperative technicians or experienced farmers, ensuring that coordination and decision-making remain based on field expertise. Evaluation metrics should also reflect tangible farming priorities, including input reduction, simplification of work and autonomy in decision-making.

Implementing iterative and participatory development in real agricultural contexts, however, presents practical challenges. The organisation of workshops, review meetings and joint evaluation sessions can impose a significant time and cognitive load on participants, particularly in contexts characterised by seasonal workload peaks and limited human and technical resources. Farmers and local technicians often operate under tight time constraints and may have limited familiarity with iterative and participatory design methods, which can lead to fatigue, reduced motivation and ultimately weaken the continuity of participation across successive cycles. To mitigate these risks, the framework explicitly relies on facilitation and progressive familiarisation. Facilitators play a key role not only in mediating communication but also in adapting the language, pace and content of sessions to users' capabilities; while scheduling and intensity of activities are aligned with the seasonal rhythm of agricultural work to ensure continuity and inclusiveness in participation.

Methodologically, the introduction of an evaluative backlog represents a key innovation. Each user story is linked to a CBA sheet capturing tangible and intangible effects of digitalisation; time savings, productivity gains, learning costs and perceived usefulness [18]–[21]. This dual backlog aligns priorities with collectively defined value dimensions, reducing the risk of decontextualised or supply-driven innovation [8][15][24]. Iteratively updating evaluation data during field tests and review meetings narrows the temporal gap between design and assessment, a persistent weakness in agricultural innovation [29][32][33].

A further challenge concerns the complexity associated with iterative prioritisation and participatory cost–benefit evaluation. The repeated need to rank backlog elements and to assess their perceived value, can overwhelm participants or lead to overly formalised decision-making, where evaluation risks becoming a procedural exercise rather than a reflective process. To address this risk, AGILE-CBA integrates qualitative deliberation, understood as an open and structured dialogue in which stakeholders collectively reflect on and articulate the values, experiences and meanings underlying their judgments. Building on the principles of deliberative valuation [35], this approach emphasises motivation, mutual learning and the co-construction of shared understandings of value, extending evaluation beyond individual preferences and purely numerical assessments. Integrated across all evaluative steps of the framework, it fosters open discussions supported by simple visual aids during prioritisation meetings. These moments help the participants express their reasoning and experiences, ensuring that the evaluation of each option reflects a holistic understanding of value based on shared experiences and discussion rather than relying solely on formal or procedural criteria. Such reflective practices are essential to capture not only expected benefits but also potential unintended consequences of digitalisation, as shown by recent participatory studies on impact elicitation in rural systems [34].

The framework also contributes to discussions on adoption barriers in digital agriculture. Low digital literacy, trust issues and data governance concerns [4]–[7][22][23] remain major obstacles. By involving stakeholders in evaluation from the outset, AGILE-CBA turns assessment into a capacity-building process that enhances confidence and autonomy. This resonates with living lab findings showing that iterative learning and participatory reflection sustain engagement and reduce perceived risks [20][27]–[29].

Finally, the flexibility of AGILE-CBA must be preserved to accommodate the variable, weather-dependent and labour-intensive nature of farming. Although the framework draws on the Scrum paradigm, sprint durations and cycles are not fixed by time but may instead follow agronomic phases such as sowing, irrigation or harvest. This adaptation is crucial to maintain engagement and realism, avoiding procedural rigidity that would contradict the very principles of iterative learning and co-creation. The implementation of AGILE-CBA therefore requires careful calibration of temporal structures, facilitation intensity and evaluation depth, so that iterative learning can unfold within the actual constraints of agricultural systems.

Overall, AGILE-CBA provides a structured yet flexible approach to co-designing and evaluating digital innovations in agriculture. Incorporating a participatory cost-benefit assessment into iterative development, enables adaptive, inclusive and evidence-based innovation. The framework contributes to the debate on responsible digitalisation by demonstrating how iterative processes can create shared understanding, align technology with user values, and strengthen the social robustness of digital transformation. Future research should test AGILE-CBA in different contexts, exploring how institutional support and facilitation strategies influence outcomes. Integrating sector-specific models – such as risk analysis, traceability or sustainability – metrics into the evaluation backlog could further improve the relevance of decisions. In this way, AGILE-CBA serves as both a methodological tool and a conceptual bridge between technical design, impact evaluation and sustainable digital transformation in agriculture.

REFERENCES

[1] Wolfert S., Ge L., Verdouw C., Bogaardt M.-J. (2017). Big Data in Smart Farming – A review. Agricultural Systems, 153, 69–80.

[2] Balafoutis A, Beck B, Fountas S, Vangeyte J, Wal TVd, Soto I, Gómez-Barbero M, Barnes A, Eory V. (2017). Precision Agriculture Technologies Positively Contributing to GHG Emissions Mitigation, Farm Productivity and Economics. Sustainability. 2017; 9(8):1339.

[3] Rijswijk K., Klerkx L., Bacco M., Bartolini F., Bulten E., Debruyne L., Dessein J., Scotti I., Brunori G. (2021). Digital transformation of agriculture and rural areas: A socio-cyber-physical system framework to support responsibilisation. Journal of Rural Studies, 85, 79-90.

[4] Adereti D.T., Gardezi M., Wang T., McMaine J. (2024). Understanding farmers' engagement and barriers to machine learning-based intelligent agricultural decision support systems. Agronomy Journal, 116, 1237-1249.

[5] Klerkx L., Jakku E., Labarthe P. (2019). A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda. NJAS: Wageningen Journal of Life Sciences, 90–91(1), 1–16.

[6] Yeo M.L., Keske C.M. (2024). From profitability to trust: Factors shaping digital agriculture adoption. Frontiers in Sustainable Food Systems, 8, 1456991.

[7] Rotz S., Gravely E., Mosby I., Duncan E., Finnis E., Horgan M., LeBlanc J., Martin R., Neufeld H.T., Nixon A., Pant L., Fraser E. (2019). Automated pastures and the digital divide: How agricultural technologies are shaping labour and rural communities. Journal of Rural Studies, 68, 112-122.

[8] Serfilippi E., Giovannucci D., Ameyaw D., Bansal A., Wobill T. A., Blankson R., Mishra R. (2021). Benefits and Challenges of Making Data More Agile: A Review of Recent Key Approaches in Agriculture. Sustainability, 14(24), 16480.

[9] Finger R. (2023). Digital innovations for sustainable and resilient agricultural systems. European Review of Agricultural Economics, 50(4), 1277-1309.

[10] Beck K., Beedle M., van Bennekum A., Cockburn A., Cunningham W., Fowler M., Grenning J., Highsmith J., Hunt A., Jeffries R., et al. (2001). Manifesto for Agile Software Development. https://agilemanifesto.org

[11] Cockburn A. (2006). Agile Software Development: The Cooperative Game (2nd Edition). Addison-Wesley Professional.

[12] Highsmith J.A. (2002). Agile Software Development Ecosystems. Addison-Wesley Professional, Boston, Vol. 13.

[13] Schwaber K., Beedle M. (2002). Agile Software Development with Scrum. Prentice-Hall, Upper Saddle River.

[14] De Sousa K. et al. (2024). The tricot approach: an agile framework for decentralized on-farm testing supported by citizen science. A retrospective. Agronomy for Sustainable Development. 44, 8.

[15] Carolan M.S. (2019). Automated agrifood futures: robotics, labor and the distributive politics of digital agriculture. The Journal of Peasant Studies, 47, 184 - 207.

[16] Owen R., Stilgoe J., Macnaghten P., Gorman M., Fisher E., Guston D. (2013). A Framework for Responsible Innovation. In R. Owen, J. Bessant, & M. Heintz (Eds.), Responsible Innovation: Managing the Responsible Emergence of Science and Innovation in Society (pp. 27-50). John Wiley & Sons, Ltd.

[17] Klerkx L., Rose D. (2020). Dealing with the game-changing technologies of Agriculture 4.0: How do we manage diversity and responsibility in food system transition pathways? Global Food Security, 24, 100347.

[18] Papadopoulos G., Arduini S., Uyar H., Psiroukis V., Kasimati A., Fountas S. (2024). Economic and environmental benefits of digital agricultural technologies in crop production: A review. Smart Agricultural Technology, 8, 100441.

[19] Papadopoulos G., Papantonatou M., Uyar H., Kriezi O., Mavrommatis A., Psiroukis V., Kasimati A., Tsiplakou E., Fountas S. (2025). Economic and environmental benefits of digital agricultural technological solutions in livestock farming: A review. Smart Agricultural Technology, 10, 100783.

[20] Lepore F., Ortolani L., Iliopoulos C., Vergamini D., Brunori G. (2025). Assessing costs and benefits of agricultural digitalisation: the case of data collection support tools in agricultural-pastoral farms. Italian Review of Agricultural Economics (REA).

[21] Shao L., Gong J., Fan W., Zhang Z., Zhang M. (2022). Cost Comparison between Digital Management and Traditional Management of Cotton Fields - Evidence from Cotton Fields in Xinjiang, China. Agriculture, 12(8), 1105.

[22] Ebrahimi H.P., Schillo R.S., Bronson K. (2021). Systematic Stakeholder Inclusion in Digital Agriculture: A Framework and Application to Canada. Sustainability, 13(12), 6879.

[23] Kenny U., Regan Á. (2021). Co-designing a smartphone app for and with farmers: Empathising with end-users' values and needs. Journal of Rural Studies, 82, 148-160.

[24] Rose D.C., Chilvers J. (2018). Agriculture 4.0: Broadening Responsible Innovation in an Era of Smart Farming. Frontiers in Sustainable Food Systems, 2:87.

[25] Eastwood C., Klerkx L., Ayre M., Dela Rue B. (2022). Managing Socio-Ethical Challenges in the Development of Smart Farming: From a Fragmented to a Comprehensive Approach for Responsible Research and Innovation. Journal of Agricultural and Environmental Ethics, 32, 741–768.

[26] McGrath K., Regan Á., Kennedy E., Russell T. (2024). Development of an animal health testing tool to reduce antimicrobial use on farms: perceptions, implications, and needs of Irish dairy farmers and farm veterinarians. Irish Veterinary Journal, 77, 12.

[27] Lepore F., Ortolani L., Ferrari A., Fiorentini N., Mannari C., Bacco M., Brunori G. (2023), Co-design and e-governance tools for sustainable land and water management in rural areas: the experience within the DESIRA H2020 project. In 2023 IEEE International Workshop on Metrology for Agriculture and Forestry (MetroAgriFor), Pisa, Italy, 2023, pp. 25-30.

[28] Lepore F., Ortolani L., Ferrari A., Bacco M., Brunori G. (2024), Needs, Challenges and Opportunities of Digital Livestock Farming in a Cheese Supply Chain. In 2024 IEEE International Workshop on Metrology for Agriculture and Forestry (MetroAgriFor), Padua, Italy, 2024, pp. 295-300.

[29] Pawera L., Manickam R., Wangungu C., Bonnarith U., Schreinemachers P., Ramasamy S. (2024). Guidance on farmer participation in the design, testing and scaling of agricultural innovations. Agricultural Systems, 218, 104006.

[30] AlJafa H., László V. (2023). Using Agile in Implementing Agriculture AI Projects and Farm Management. Journal of Agricultural Informatics, 14(1).

[31] Mesaros D., Rusu T., Mesaros I. (2022). Agile Scrum Applied in Agricultural Processes. The Scientific Bulletin of Electrical Engineering Faculty, 22(1), 1-5.

[32] Blix Germundsson L., Papadopoulou E., Jönsson H., Dimitrievski I., Moudrý J., Melin M. (2024). Participatory ex-ante impact assessment for interactive research and development in agriculture and food systems. Impact Assessment and Project Appraisal, 42(2), 160–172.

[33] McCampbell M., Schumann C., Klerkx L. (2022). Good intentions in complex realities: Challenges for designing responsibly in digital agriculture in low-income countries. Sociologia Ruralis, 62(2), 279-304.

[34] MacPherson J., Rosman A., Helming K., Burkhard B. (2025). A participatory impact assessment of digital agriculture: A Bayesian network-based case study in Germany. Agricultural Systems, 224, 104222.

[35] Kenter J.O., Reed M.S., Fazey I. (2016). The Deliberative Value Formation model. Ecosystem Services, 21, 194-207.

[36] Ferrari A., Lepore F., Ortolani L., Brunori G. (2023), *Eliciting the Double-edged Impact of Digitalisation: a Case Study in Rural Areas*. 2023 IEEE 31st International Requirements Engineering Conference (RE), Hannover, Germany, 2023, pp. 157-168.