A Data Governance Framework for Socio-Ecological Value in Smart Agriculture

Saeed Niksaz
Department of Informatics
Linnaeus University
Kalmar, Sweden
saeed.niksaz@lnu.se

Fisnik Dalipi
Department of Informatics
Linnaeus University
Kalmar, Sweden
fisnik.dalipi@lnu.se

Avni Rustemi
Department of Informatics
University of Tetovo
Tetovo, North Macedonia
avni.rustemi@unite.edu.mk

***Abstract*—The digital transformation of agriculture has accelerated the adoption of data-driven technologies such as IoT sensors, satellite imagery, blockchain, and artificial intelligence. However, small and medium-sized farms often face structural challenges related to data governance, interoperability, and equitable value creation, limiting the sustainable use of digital innovations. This paper proposes a farmer-centric data governance and analytics framework that integrates heterogeneous farm data sources into a socio-ecological value assessment system. The framework combines low-cost data collection tools, including IoT sensors, mobile applications, cooperative surveys, and administrative records, with secure data processing pipelines and traceable storage mechanisms. At its core, a socio-ecological value scorecard (SEVS) aggregates ecological, social, and economic indicators to support balanced decision-making that aligns short-term productivity with long-term sustainability. The framework operationalizes governance principles such as transparency, shared responsibility, and data sovereignty through practical policies, cooperative stewardship, and accessible technical mechanisms. The proposed model contributes to smart agriculture research by demonstrating how governance-aware data architectures can enable inclusive, trustworthy, and sustainable digital farming practices.**

Keywords—Socio-Ecological Value Scorecards, Data Governance, Smart Agriculture, Farmer Data Sovereignty, Algorithmic Transparency, Sustainability Assessment.

I. Introduction

Agriculture stands at a critical juncture where the promise of digital transformation confronts fundamental questions about power, equity, and sustainability. The expansion of Internet of Things (IoT) sensors, artificial intelligence, big data analytics, and precision farming technologies has generated massive volumes of agricultural data and created opportunities to manage resource use, increase productivity, and diminish climate challenges [1, 2]. However, this data revolution presents considerable governance challenges. Critical research demonstrates that digital platforms in agriculture can transform the daily lives of farmers, practices, social networks, and identities [3]. In addition, the implementation of sustainability metrics faces tensions regarding their ability to capture the complexity of diverse farming practices, the alignment of these metrics with principles of farmers, and the effect of metrics on the independence of farmers [4].

Socio-ecological value scorecards (SEVS) can serve as institutionalized valuation and governance frameworks that define, measure, and encourage sustainable agricultural practices to address these challenges [5]. Instead of focusing only on productivity, sustainability, and profitability, SEVS also measures environmental factors (like soil health, water quality, and CO_2 emission), social factors (such as working conditions, worker safety, and skill development), and governance factors (including data ownership and equal access to digital technologies) together in a holistic assessment framework.

Basically, SEVS can be represented as a composite function:

$$V = f\,(E, S, I; w, r) \tag{1}$$

In this equation, V refers to SEVS, E represents ecological dimensions, S captures social factors, I encompasses institutional elements, w indicates how different stakeholders assign importance to these factors, and r defines the rules and algorithms governing aggregation and trade-off management. Digital transformation reshapes SEVS implementation by acting on (E, S, I) through measurement and data integration and on (w, r) by algorithm design and platform governance. However, this digitalization is also political. According to [6], in their socio-cyber-physical systems framework, digital transformation creates new forms of responsibility where farmers are increasingly judged by standard performance measures. At the same time, they may be facing risks and loss of autonomy over their decisions. Similarly, authors in [7] illustrate how socio-cyber-physical assemblages in diversified farming systems create complex networks of humans, technologies, and physical resources that reshape data collection, sharing, and governance practices.

Control over data infrastructures is fundamental to data governance, whereas digital sustainability assurance shows how this control can create new digital lead actors that coordinate and discipline suppliers within value chains [8]. Without clear governance frameworks, SEVS implementations could turn into instruments of private or governmental surveillance, and impact selections of farmers by means of unclear algorithmic systems. Farmers may lose their control over the data produced from their land and labor, which can lead to serious worries about privacy, fair distribution of benefits, and rights related to food systems. Despite the increase in these challenges, the literature is lacking in comprehensive theoretical frameworks that tackle the governance aspect imperative for the successful implementation of SEVS. Many studies tend to focus on specific aspects like farmer data sovereignty [9], blockchain-based trust mechanisms [10], participatory approaches [11], and policy frameworks [12], without merging these elements into a coherent governance model.

This study poses the following research question: *What data governance model is required to operationalize socio-ecological value scorecards in smart and small-scale farming systems, ensuring that such scorecards are visible, usable, and actionable for farmers and other stakeholders?*

To answer this question, the paper addresses the existing gap by developing a data governance framework designed for SEVS implementation in smart agriculture settings. The framework includes a governance model that: (1) ensures farmer control over data generated from their farm and labor; (2) establishes transparency and makes the methods used to choose and combine indicators; (3) creates fair benefit-sharing systems that encourage data sharing and protecting privacy; and (4) facilitate negotiation among multiple stakeholders and reflection on scorecard parameters.

II. Background and Related Works

The digital transformation of agriculture entails the management of activities across the value chain through the collection, integration, and analysis of diverse data types such as geospatial information, behavioral patterns, phytosanitary conditions, consumption metrics, energy usage, and economic indicators [13]. While digital tools can improve productivity, profitability and sustainability, they may also threaten farmer autonomy, weaken experiential knowledge, and increase dependency on technology providers [4].

Data governance in agriculture enables increased security, privacy, and preservation of data integrity by establishing clear rules, procedures, and responsibilities among farmers and other stakeholders involved in the agricultural network [14]. With the use of contemporary technologies such as IoT, blockchain, and AI, agriculture has been transferred to smart agriculture, with the aim of increasing productivity and reducing costs. The implementation of smart agriculture requires numerous intelligent devices, which communicate and produce large amounts of data, a clear governance structure, and communication through secure protocols to restore trust between farmers and other actors involved in the agricultural chain [15]. The use of clear models and protocols for data governance also enables higher interoperability and data sharing [16]. Standardization, increased innovation in technology, data transparency and good management through clear, transparent policies enable, among other things, the optimization of agricultural practices, the reduction of costs and potential losses, and, above all, the creation of a long-term strategy for financial planning and possible investments in the future [17].

From technical standpoint, an important role in the implementation and management of data governance models is also played by the application of federated learning [18]. Detecting various diseases, predicting yields in agricultural products, predicting rainfall, monitoring the health of various plants and animals, detecting various objects that can damage or improve performance both in communication and in increasing productivity, are just some of the practical implementations of federated learning. Hence, federated learning has a positive impact on preserving data privacy by localizing them on farms through devices distributed in different areas, which can communicate with each other even with unstable internet connections [18].

A comprehensive governance model typically encompasses the active involvement of all stakeholders, the use of data analytics and their deployment across organizational units. Key categories for data governance in agriculture include data security and encryption, privacy and compliance with relevant regulations, and mechanisms for transparent data sharing and secure interaction among actors [19].

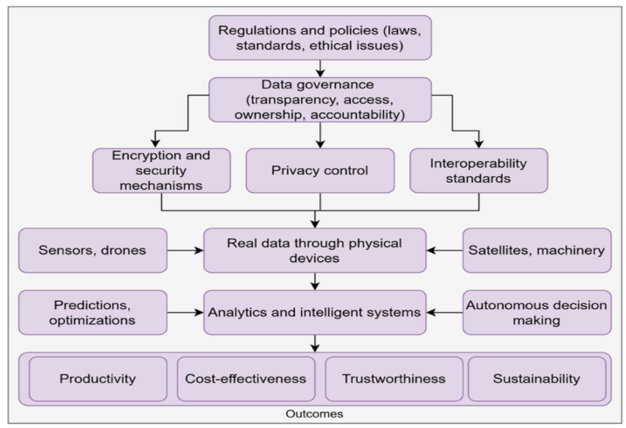

Fig. 1. Conceptual model of data governance in agricultural systems

Figure 1 depicts a high-level conceptual model of data governance in agricultural systems. The model foregrounds the role of regulations and policies as the normative foundation of the agricultural data ecosystem, from which data governance principles, such as transparency, access, ownership, and accountability, are operationalized. Building on this foundation, the model integrates technical mechanisms for security, privacy, and interoperability with data acquisition through physical devices, thereby enabling analytics, prediction, and decision-making processes. In turn, these processes support the translation of empirical data into economic, social, and ecological value for agricultural systems, ultimately contributing to enhanced productivity, cost-effectiveness, trustworthiness, and sustainability.

In recent years, a variety of sustainability assessment tools have emerged in the agricultural domain; however, substantial limitations persist. Existing tools predominantly emphasize environmental and economic dimensions, while social indicators are frequently neglected or insufficiently aligned with the lived experiences of farmers [20]. This imbalance highlights two interrelated issues: first, the inherent difficulty of operationalizing and measuring social factors; and second, the tendency of dominant actors to privilege quantifiable, market-oriented metrics over qualitative, and context-sensitive values.

Socio-ecological value scorecards address these shortcomings by advancing a more integrated approach to sustainability assessment, incorporating environmental, social, and economic dimensions within a unified evaluative framework. Instead of equating agricultural performance solely with yield or profit maximization, SEVS reconceptualizes it as the concurrent pursuit of ecological stewardship, social equity, and economic viability. In doing so, it responds to the limitations of prevailing tools by introducing indicators that are sensitive to situated realities of farmers and local contexts, thereby shifting sustainability assessment from a predominantly market-driven exercise toward a broader socio-ecological appraisal [21].

A. *The challenges of adopting data governance models in agriculture*

Digitalization of agriculture systems introduces new governance challenges. Platform architectures influence which stakeholders can access, contribute to, and gain benefits from data, leading to "digital lead actors" who gain too much control [22]. Effective governance must tackle various challenges involving technical, legal, economic, social, and ethical dimensions.

From a technical perspective, many rural regions encounter infrastructural constraints [23]. Even where infrastructure exists, interoperability challenges due to varied and non-standardized data sources limit integration and hinder the creation of strong data ecosystems [24]. The heterogeneity of different data collection sources, the lack of formats and standardization of real-time processing from various edge devices installed across agricultural lands are also challenges that data governance models are facing in practice. Moreover, the lack of documentation of the development of agricultural products, i.e., traceability and transparency, results in a loss of trust and prevents farmers from making decisions based on processed data [25].

At the same time, legal and regulatory frameworks governing agricultural data remain incomplete despite recent legislative efforts. Since non-personal agricultural data is not covered by personal data protection laws like the General Data Protection Regulation (GDPR) [26], its management presents unique regulatory challenges that require different institutional and legal strategies. In this regard, the EU Code of Conduct on Agricultural Data Sharing [27] represents an effort that clearly separates agricultural data, such as farm operations, machine data, and field-level records, from personal data, providing guidelines for fair data access, sharing, and usage among agricultural stakeholders. However, it lacks binding enforcement, and smart farming technologies must still carefully assess whether collected data can be linked back to identifiable individuals, in which case GDPR regulations must be followed. Farmers produce significant amounts of non-personal data; however, there is no extensive legal framework that clearly acknowledges their ownership of this data. Consequently, control is often vaguely shifted through contractual agreements [28]. Data ownership and legal issues regarding the identity of data, who owns it and who has the right to use it, and the possibility of its misuse are also challenges that farmers are facing in terms of legal legislation and work rules [29].

Other challenges related to the adoption of governance models on farms include institutional and organizational barriers, because there is no adequate division of responsibilities, on authorized persons and definition of roles in data management [16]. The deployment of IoT devices, data storage platforms, security and encryption mechanisms, and other intelligent systems integral to contemporary smart farming presents significant economic and infrastructural challenges for farmers. These obstacles are particularly acute in rural areas, where resource constraints remain prevalent [14]. Additionally, inadequate documentation of agricultural product development, manifested as deficiencies in traceability and transparency, erodes stakeholder trust to leverage processed data for informed decision-making [25].

To address these issues, the paper proposes a comprehensive framework that considers data governance as an essential element of SEVS design, shaping whose values are recognized, who gains benefits, the role of feedback loops to improve the data governance, and how sustainability shifts take place in smart farming.

III. Towards an Integrated Data Governance Model Architecture

In order to translate the conceptual principles outlined in Figure 1 into actionable system tailored to the realities of SMEs and smallholder context, in Figure 2, we present an operational and practice-oriented architecture for small-scale farm data governance, analytics, and decision support.

The model begins with the integration of six primary categories of farm-level data sources, reflecting the heterogeneity and low-cost nature of data generation in small-scale agriculture. Smartphone applications capture environmental and operational data such as weather forecasts, biodiversity observations, automated irrigation controls, real-time monitoring, and critical alerts that support immediate decision-making. Drone imagery and satellite data, often combined with platforms such as Google Earth, provide seasonal snapshots of crop health, enabling spatial analysis of growth patterns, pest outbreaks, and stress conditions. Cooperative surveys contribute annual and seasonal community input through participatory design processes, capturing social and organizational dimensions that are typically invisible to purely technical sensors. Administrative records maintained in Excel sheets support the tracking of sales logs, expense records, local market signals, and supply-chain activities. Finally, IoT sensors continuously monitor soil moisture, pressure, pest and disease indicators, and irrigation systems, forming the backbone of real-time environmental data collection.

At the center of the architecture lies the SME data governance core, which operationalizes data governance principles in a manner that is accessible, equitable, and context-sensitive. Rather than relying on complex technical infrastructures, the governance core emphasizes low-cost data ingestion, secure transmission, ethical data use, and alignment with farmers' experiential knowledge. Governance is enacted through practical policies, simple non-technical checklists, and a rotating cooperative steward role, ensuring shared responsibility, balanced power relations, and fair distribution of benefits. This approach mitigates risks of data monopolization

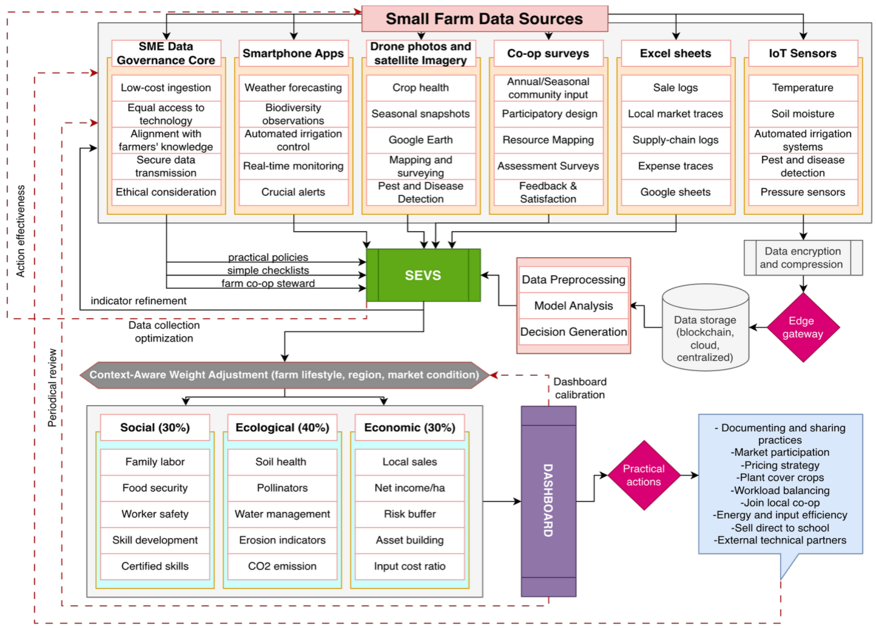

Fig. 2. Architecture of the proposed data governance model.

and reinforces trust, accountability, and inclusivity within farming communities.

Data originating from physical devices and digital records flow through edge gateways, where encryption and compression mechanisms enhance security and efficiency before entering the processing layer. In this phase, machine learning, artificial intelligence, computer vision, and large language models transform raw, heterogeneous data into structured and interpretable information. Processed data are stored across complementary infrastructures—blockchain solutions to ensure traceability, SQL databases for structured querying, and distributed architectures to support data sovereignty and resilience—balancing performance, transparency, and ownership concerns.

The SEVS functions as the central analytical "engine" of the model. It integrates multi-source data into a balanced assessment framework weighted across ecological (e.g., 40%), social (30%), and economic (30%) dimensions, thereby reconciling long-term sustainability goals with short-term economic viability. Ecological indicators include soil health, pollinator diversity, water management efficiency, erosion metrics, and CO_2 emissions. Social indicators assess family labor equity, food security, worker safety, community contribution, skill development, and certification levels. Economic indicators capture local sales proportions, net income per hectare, risk buffer capacity, asset building, and input cost efficiency. Importantly, these weights are not static; they are dynamically adjusted based on farm life cycle stages, regional ecological priorities, and prevailing market conditions, enabling context-aware and adaptive sustainability assessments. Insights generated by SEVS are translated into actionable knowledge through an interactive dashboard, which visualizes performance using intuitive traffic-light indicators. Green signals stable or positive performance, yellow highlights emerging risks or areas requiring attention, and red denotes critical issues demanding immediate intervention. Weekly insights provide farmers with concise updates summarizing overall performance, priority actions, recent progress, preparation needs, and peer-learning examples from successful cooperative members. This continuous feedback loop supports learning, reflection, and timely adjustment of farming practices.

Finally, the system generates dimension-specific recommendations that connect analytics to concrete actions. Ecological recommendations include documenting and sharing sustainable practices, planting cover crops, improving soil health, and engaging external technical partners. Social recommendations address market participation strategies, pricing decisions, cooperative engagement, and workload balancing to support farmer well-being. Economic recommendations focus on energy and input efficiency, diversification of sales channels such as farm-to-school programs, and the development of strategic partnerships.

IV. Feedback Loop Analysis

Effective data governance frameworks are not fixed systems. They must evolve in response to changing farm conditions, emerging data patterns, and shifting stakeholder needs. In the case of SEVS, feedback loops serve as the mechanism through which the framework achieves this adaptability. Without structured feedback, the scorecard risks becoming a fixed assessment tool that loses relevance over time. They help improve data collection methods, adjust indicator weights, assess whether recommended actions are effective, and ensure that governance rules reflect actual farm outcomes. To support this adaptive approach, the framework includes four types of feedback loops: the *Periodical Review Cycle*, *Data Collection Optimization*, *Dashboard Calibration*, and *Action Effectiveness Validation*.

A. Periodical Review Cycle

Since farmers implement practical actions, these interventions change farm conditions shown by the data collection cycle. Improved ecological indicators generate green dashboard signals that validate farmer efforts and strengthen commitment to sustainable practices. Enhanced economic indicators provide financial resources for investments in socio-ecological improvements. Strengthened social networks increase problem-solving capacity and generate better action recommendations. Therefore, a periodical cycle is important to continuously monitor outcomes, and manage decisions so that ecological, economic, and social improvements can be sustained over time.

B. *Data Collection Optimization*

When the dashboard indicates that specific data sources have a small impact on decision-making or action recommendations, the governance core reduces collection frequency or eliminates those sources completely. For instance, if weekly soil moisture readings show minimal variation and do not influence irrigation decisions, collection might shift to monthly. This loop guarantees scorecard sustainability through continuously optimizing which data to collect. Thus, the scorecard maintains relevance and practicality and tackles a major obstacle to adoption in resource-limited environments.

C. *Dashboard Calibration*

This loop modifies the weights of indicators in each scorecard dimension when particular indicators are found to be more predictive of overall farm resilience than others. This loop addresses the problem that the same standards do not work everywhere. For example, a soil health level that is suitable in cooler climates might not make sense in drier regions. The scorecard stays practical locally by adjusting standards based on how well they work in each area and allows comparisons across different regions.

D. *Action Effectiveness Validation*

When farmers use specific methods, they document implementation details, resource investments, challenges they face and observed results. The governance core collects this data across multiple farms and seasons in order to identify which practices improve indicators, which fail despite theoretical promise, and which work only in specific areas. The SEVS incorporates this knowledge and indicators or methods if current measures fail to respond to effective practices. This loop transforms the scorecard from a passive measurement tool into an active learning system. In contrast to static sustainability evaluations that assume stable relationships between practices and outcomes, this approach recognizes that effectiveness can be identified through systematic experimentation and feedback.

V. Discussion

The proposed framework responds to the research question by articulating a governance model that simultaneously ensures farmer data sovereignty, promotes algorithmic transparency, engages social indicators, and facilitates fair benefit-sharing. These governance functions together tackle the issues identified in prior studies, where farmer data sovereignty, blockchain-based trust, participatory design, and policy frameworks have all been analyzed separately without merging into a unified operational framework.

SEVS aims to address issues of agricultural data ownership, digitalization of farms, and addressing ethical and legal issues moving in this direction into an intelligent decision-making ecosystem. In this regard, SEVS would also facilitate the evaluation of multidimensional indicators across different local contexts, with the aim of proactive and intelligent management in agriculture, and thereby transforming the scorecard from an assessment and analysis tool into a sustainable platform for rational decision-making for farmers [5, 21]. Through standardizing data governance models that include the measurement of economic, social, and ecological metrics, which integrate blockchain technology for higher security and AI models for automatic recommendations, SEVS can be a perfect model for the sustainability of smart agriculture.

Compared with static sustainability assessment tools that have been criticized for failing to capture the social dimensions of farming [20], feedback loops of the proposed framework transform the scorecard from a passive tool into a dynamic learning system, which is a differentiation that brings significant consequences for practical implementation.

The technical architecture of the framework addresses important infrastructure challenges identified in the literature [23, 24]. The design focuses on the digital divide impacting smallholder farmers through combining affordable and varied data sources such as smartphone applications, collaborative surveys, and Excel records, along with sensor networks to promote more accessible data governance. Moreover, the framework seeks to mitigate algorithmic transparency risks by employing clear indicator selection in terms of farm style, region, market condition, and a dashboard calibration cycle.

Nevertheless, the success of SEVS depends on the digital literacy of farmers and their engagement. This limitation indicates the necessity for future testing across different agricultural contexts. The suggested governance framework is theoretical, the structure and its related feedback mechanisms have not been tested or confirmed in real farming contexts. As a result, assertions are still theoretically driven rather than empirically validated. Furthermore, the regulatory framework concerning non-personal agricultural data is still immature in various areas [28], stating that the governance protections suggested here might lack implementable support in specific situations. Future studies will include pilot project in various agri-food systems to empirically evaluate barriers in different contexts. This involves applying the framework in various regional and ecological settings to evaluate the indicators weights, feedback loop mechanisms, and governance policies.

VI. Conclusion

This paper made three principal contributions to the intersection of smart agriculture and data governance in order to improve the farm performances in terms of sustainability, productivity and profitability. First, it clarified and extended the SEVS concept by defining it as a composite governance function and illustrating how each component is shaped by digital transformation in agriculture. Second, it identified and characterized an essential scarcity in the existing literature. Although individual governance mechanisms have been studied in relative isolation, no prior work has integrated these elements into a unified operational model that enables SEVS implementation in actual agricultural systems. Third, this paper proposed an integrated data governance architecture that addresses this gap through data acquisition strategies, processing data, storage technologies, scorecard weighting logic, dashboard and visualization tool, and adaptive feedback loops that together allow the scorecard to operate as a dynamic governance tool instead of a fixed assessment model. These contributions give clear guidance for farmers, cooperatives, technology developers, and policymakers who seek to design responsible digital sustainability frameworks in agriculture.

The governance framework proposed here carries practical implications for different stakeholders by promoting data management, transparent governance standards, providing clearer legal protections, and fostering interdisciplinary research in smart agriculture.

REFERENCES

[1] S. Wolfert, L. Ge, C. Verdouw, and M.-J. Bogaardt, "Big data in smart farming–a review," *Agricultural systems,* vol. 153, pp. 69-80, 2017.

[2] C. Parra-López *et al.*, "Integrating digital technologies in agriculture for climate change adaptation and mitigation: State of the art and future perspectives," *Computers and Electronics in Agriculture,* vol. 226, p. 109412, 2024.

[3] M. Carolan, "Agro-Digital Governance and Life Itself: Food Politics at the Intersection of Code and Affect," *Sociologia Ruralis,* vol. 57, no. S1, pp. 816-835, 2017, doi: https://doi.org/10.1111/soru.12153.

[4] M. Hatanaka and J. Konefal, "Governing by data: metrics and sustainability in produce agriculture," *Agriculture and Human Values,* vol. 42, no. 1, pp. 289-301, 2025/03/01 2025, doi: 10.1007/s10460-024-10606-y.

[5] S. Niksaz and F. Dalipi, "Designing a Socio-Ecological Value Scorecard: A Holistic Approach to Farm Performance and Sustainability," in *Distributed, Ambient and Pervasive Interactions*, Cham, N. A. Streitz and S. i. Konomi, Eds., 2025// 2025: Springer Nature Switzerland, pp. 119-129.

[6] K. Rijswijk *et al.*, "Digital transformation of agriculture and rural areas: A socio-cyber-physical system framework to support responsibilisation," *Journal of Rural Studies,* vol. 85, pp. 79-90, 2021.

[7] M. Metta, J. Dessein, and G. Brunori, "Between on-site and the clouds: Socio-cyber-physical assemblages in on-farm diversification," *Journal of Rural Studies,* vol. 105, p. 103193, 2024.

[8] S. R. Kruk, H. M. Toonen, and S. R. Bush, "Digital sustainability assurance governing global value chains: The case of aquaculture," *Regulation & Governance,* vol. 18, no. 4, pp. 1153-1170, 2024.

[9] C. Gans Combe and S. Camaréna, "Data sovereignty and valuation model for sustainable agriculture innovation and equity," *npj Sustainable Agriculture,* vol. 3, no. 1, p. 61, 2025/11/18 2025, doi: 10.1038/s44264-025-00102-z.

[10] A. Vangala, A. K. Das, N. Kumar, and M. Alazab, "Smart secure sensing for IoT-based agriculture: Blockchain perspective," *IEEE Sensors Journal,* vol. 21, no. 16, pp. 17591-17607, 2020.

[11] S.-L. Ruder and H. Wittman, "Agricultural data governance from the ground up: Exploring data justice with agri-food movements," *Big Data & Society,* vol. 12, no. 1, p. 20539517251330182, 2025, doi: 10.1177/20539517251330182.

[12] M.-A. Jouanjean, F. Casalini, L. Wiseman, and E. Gray, "Issues around data governance in the digital transformation of agriculture: The farmers' perspective," *OECD Food, Agriculture and Fisheries Papers,* 2020.

[13] L. Klerkx, E. Jakku, and P. Labarthe, "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,* vol. 90, no. 1, pp. 1-16, 2019.

[14] C. S. Sullivan, M. Gemtou, E. Anastasiou, and S. Fountas, "Building trust: A systematic review of the drivers and barriers of agricultural data sharing," *Smart Agricultural Technology,* vol. 8, p. 100477, 2024/08/01/ 2024, doi: https://doi.org/10.1016/j.atech.2024.100477.

[15] A. Rustemi and F. Dalipi, "Synergizing IoT, AI, and blockchain for smart agriculture: Challenges, opportunities, and future directions," *Internet of Things,* vol. 34, p. 101778, 2025/11/01/ 2025, doi: https://doi.org/10.1016/j.iot.2025.101778.

[16] M. Devare, E. Arnaud, E. Antezana, and B. King, "Governing Agricultural Data: Challenges and Recommendations," in *Towards Responsible Plant Data Linkage: Data Challenges for Agricultural Research and Development*, H. F. Williamson and S. Leonelli Eds. Cham: Springer International Publishing, 2023, pp. 201-222.

[17] J. Li and Y. Yu, "Impact of government public data openness on agricultural total factor productivity," *International Review of Economics & Finance,* vol. 104, p. 104561, 2025/12/01/ 2025, doi: https://doi.org/10.1016/j.iref.2025.104561.

[18] R. Dembani, I. Karvelas, N. A. Akbar, S. Rizou, D. Tegolo, and S. Fountas, "Agricultural data privacy and federated learning: A review of challenges and opportunities," *Computers and Electronics in Agriculture,* vol. 232, p. 110048, 2025/05/01/ 2025, doi: https://doi.org/10.1016/j.compag.2025.110048.

[19] R. Rouzky, A. Sarrafzadeh, E. Sowells-Boone, H. B. Pasandi, and G. Goins, "Data governance in smart farming: A systematic review of challenges and gaps," *Information Processing in Agriculture,* 2025/12/03/ 2025, doi: https://doi.org/10.1016/j.inpa.2025.11.006.

[20] E. Röös, K. Fischer, P. Tidåker, and H. Nordström Källström, "How well is farmers' social situation captured by sustainability assessment tools? A Swedish case study," *International Journal of Sustainable Development & World Ecology,* vol. 26, no. 3, pp. 268-281, 2019.

[21] S. Niksaz, F. Dalipi, and A. Mirijamdotter, "A systematic literature review on socio-ecological value scorecards for advancing sustainable smart agriculture," *Discover Sustainability,* vol. 6, no. 1, p. 838, 2025/08/17 2025, doi: 10.1007/s43621-025-01682-z.

[22] M. Kenney, H. Serhan, and G. Trystram, "Digitalization and platforms in agriculture: organizations, power asymmetry, and collective action solutions," ETLA Working Papers, 2020.

[23] Y. Sun, Y. Miao, Z. Xie, and R. Wu, "Drivers and barriers to digital transformation in agriculture: An evolutionary game analysis based on the experience of China," *Agricultural Systems,* vol. 221, p. 104136, 2024/12/01/ 2024, doi: https://doi.org/10.1016/j.agsy.2024.104136.

[24] O. Rozenstein *et al.*, "Data-driven agriculture and sustainable farming: friends or foes?," *Precision Agriculture,* vol. 25, no. 1, pp. 520-531, 2024/02/01 2024, doi: 10.1007/s11119-023-10061-5.

[25] M. Pincheira, F. Antonelli, and M. Vecchio, "AGRICLIMA: Towards a Federated Platform for Spatiotemporal Risk Analysis in Agriculture," *Agriculture,* vol. 15, no. 23, p. 2450, 2025. [Online]. Available: https://www.mdpi.com/2077-0472/15/23/2450.

[26] P. Voigt and A. Von dem Bussche, "The eu general data protection regulation (gdpr)," *A practical guide, 1st ed., Cham: Springer International Publishing,* vol. 10, no. 3152676, pp. 10-5555, 2017.

[27] C. Copa *et al.*, "EU Code of Conduct on Agricultural Data Sharing by Contractual Agreement," Copa-Cogeca, Brussels, Belgium, 2018. [Online]. Available: https://www.copa-cogeca.eu/img/user/files/EU%20CODE%20OF%20CONDUCT/EU_Code_of_conduct_EN_2018_web.pdf

[28] F. Berisha, P. Mooney, Z. Pourzolfaghar, and M. Helfert, "Shared Yet Owned: The Dual Path of Data Ownership in Agriculture: A Systematic Review," *Data & Policy,* vol. 8, p. e3, 2026, Art no. e3, doi: 10.1017/dap.2025.10050.

[29] C. Atik, "Towards Comprehensive European Agricultural Data Governance: Moving Beyond the "Data Ownership" Debate," *IIC - International Review of Intellectual Property and Competition Law,* vol. 53, no. 5, pp. 701-742, 2022/05/01 2022, doi: 10.1007/s40319-022-01191-w.