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Agricultural Data Markets in Precision Farming: A Policy Framework for Ownership, Interoperability, Privacy, Competition, and Farmer Protection

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Abstract

Agricultural data markets are becoming integral to precision farming as data generated by sensors, machinery, remote-sensing systems, farm-management platforms, advisory services, supply chains, and public information infrastructures acquire operational and economic value. However, the expansion of data exchange creates policy challenges that cannot be assessed through innovation, productivity, or monetization potential alone. This article develops an original policy framework that connects agricultural data-market boundaries, actors, data flows, ownership claims, access arrangements, effective control, farmer participation, privacy, competition, platform power, interoperability, fair exchange, accountability, and implementation safeguards. The framework distinguishes data ownership from access, control, portability, consent, and practical farmer agency. It also treats privacy protection as one component of a wider governance architecture that must address platform dependency, market concentration, switching costs, asymmetric information, bargaining-power imbalances, data-intermediary influence, and unclear accountability. Interoperability is conceptualized as a combination of technical, semantic, organizational, and governance conditions rather than as a sufficient guarantee of fair exchange. The framework further identifies policy gaps involving ambiguous rights, fragmented portability, weak consent, opaque value capture, deficient dispute pathways, and limited monitoring capacity. Its principal contribution is a structured policy-analysis model that links risk identification to context-sensitive safeguards, stakeholder feedback, monitoring, and framework updating. The framework supports policy-oriented analysis but does not independently establish legal compliance, guarantee farmer protection, certify market fairness, or demonstrate implementation readiness.

Keywords Precision farming, Data ownership, Interoperability, Privacy, Agricultural data markets, Competition

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Introduction

Precision farming increasingly depends on the continuous production, combination, and interpretation of sensor data, machine data, soil information, crop records, weather observations, remote-sensing outputs, livestock information, and operational farm data. These data move through connected relationships involving farmers, agricultural advisors, equipment manufacturers, input suppliers, technology providers, digital platforms, data intermediaries, cooperatives, supply-chain organizations, research bodies, and public institutions. Such relationships form agricultural data ecosystems in which technical infrastructures, commercial services, institutional arrangements, and governance choices jointly determine how data are collected, accessed, reused, transferred, and converted into decision-support or economic value.

Consequently, agricultural data markets should be understood as socio-technical arrangements rather than as neutral mechanisms for transferring digital resources [1, 2].

The policy significance of these markets arises from the capacity of digital technologies to redistribute informational control, decision-making influence, labour relations, and value capture across agricultural systems. Data-intensive services can enhance monitoring, forecasting, automation, and coordination, yet the same infrastructures may deepen dependence on proprietary platforms, consolidate commercial influence, reduce farmers' practical control over their operational histories, and produce unequal access to digital capabilities. These effects are not inevitable, but they demonstrate why data-market evaluation must consider who controls technical interfaces, who defines permissible uses, who possesses analytic capacity, who can exit an ecosystem, and who benefits from aggregated agricultural information [3].

A policy approach must therefore move beyond fragmented treatment of ownership, privacy, interoperability, competition, and farmer protection as separate concerns. Responsible governance requires anticipation of possible consequences, meaningful inclusion of affected actors, reflexive examination of institutional assumptions, and responsiveness to evidence emerging during implementation. These requirements are particularly important because agricultural data arrangements may evolve rapidly as platforms expand, business relationships change, data sources are combined, and new analytic uses emerge. A governance model that remains fixed at the point of initial consent or contractual acceptance may fail to respond to later changes in data value, market power, downstream use, or farmer vulnerability [4].

This article proposes an original policy framework for agricultural data markets in precision farming. Its objective is to integrate agricultural data-market boundary definition, stakeholder mapping, data-flow analysis, ownership and access assessment, farmer-protection assessment, privacy evaluation, competition and platform-power analysis, interoperability review, fair data-exchange assessment, policy-gap identification, safeguard selection, implementation-risk review, monitoring, accountability, stakeholder feedback, and framework updating. The contribution is analytical rather than legally prescriptive: the framework can structure policy discussion, clarify governance risks, and identify evidence needs, but it does not determine jurisdiction-specific rights, establish regulatory compliance, guarantee farmer protection, certify fair competition, or prescribe a mandatory market design.

Agricultural Data Markets as a Policy Challenge

Agricultural data markets encompass more than formal marketplaces in which datasets are directly bought or sold. They also include contractual and infrastructural arrangements through which farm data are exchanged for advisory services, equipment functionality, predictive analytics, benchmarking, risk assessment, supply-chain coordination, research access, or platform participation. Value may be captured through subscription services, complementary product sales, improved algorithmic performance, aggregated intelligence, data-enabled market positioning, or operational efficiencies rather than through an explicit data price. The resulting market is therefore shaped by the design of data infrastructures and by the conditions governing participation, interpretation, aggregation, and value capture [5].

The distribution of these benefits is unlikely to be uniform. Farmers differ in scale, capital, connectivity, technical capability, advisory access, data literacy, and negotiating position. A system that appears accessible at the level of technology availability may remain difficult to use or economically disadvantageous for farms lacking compatible machinery, reliable connectivity, staff capacity, or independent advice. Agricultural data-market policy should consequently examine both formal participation opportunities and substantive access to benefits. Innovation potential does not demonstrate equitable distribution, and data generation by farmers does not ensure that they will receive corresponding economic, informational, or operational value [6].

Supply-side structures further complicate the policy landscape. Equipment manufacturers, agricultural input firms, software developers, platform providers, telecommunications actors, analytics companies, investors, and public organizations can influence which technologies become available, which data formats dominate, which services are

bundled, and which actors control critical interfaces. Their roles may overlap: an equipment provider may operate a platform, an input supplier may offer analytics, and a data intermediary may also control access to a marketplace or advisory network. Actor mapping is therefore necessary to reveal vertically integrated relationships, commercial dependencies, conflicts of interest, and public–private interactions that may otherwise remain hidden within descriptions of a generic agricultural data ecosystem [7].

Data access can also become a competitive resource when historical farm records, machine-generated information, or platform-specific datasets are difficult to transfer or replicate. Restricted interfaces, proprietary formats, incomplete exports, long migration processes, and contractual limitations may raise switching costs for farmers and entry barriers for complementary service providers. These conditions can reinforce first-mover advantages and platform dependency even where nominal alternatives exist. Policy analysis should assess whether access restrictions are technically necessary, proportionate to legitimate security or quality concerns, transparently explained, and subject to meaningful review. Such assessment can clarify competition risks without assuming that every access restriction is unlawful or that portability alone will produce a fair market [8].

Ownership, Access, and Farmer Protection

Farmers commonly describe data generated through their land, machinery, animals, labour, and production activities as “their data,” yet ownership terminology may conceal important differences between generation, possession, access, control, use, reuse, portability, and economic benefit. Farmer reluctance to share data is often linked to uncertainty about who can retrieve information, how it will be combined, whether it will be transferred onward, and what benefits or risks may follow. Trust is weakened when data practices are opaque or when farmers cannot understand how value is distributed. Ownership language is therefore insufficient unless it is accompanied by transparent use conditions, meaningful control, and credible benefit-sharing arrangements [9, 10].

Farmer protection should also be understood as a participatory governance process rather than as a bundle of provider-defined assurances. Farmers and farm organizations need opportunities to influence data-sharing purposes, access arrangements, platform rules, consent procedures, dispute mechanisms, and framework revisions. Participation must be capable of affecting decisions; invitations to consultations or the presentation of standardized terms do not necessarily establish farmer agency. Context also matters because farmers may hold different views about collective sharing, commercial reuse, public-interest research, cooperative stewardship, or the involvement of agricultural advisors. Policy frameworks should therefore permit plural forms of participation while ensuring that less-resourced farmers are not excluded from deliberation [11].

A comprehensive policy assessment must distinguish nominal ownership from effective control. Ownership claims may be difficult to apply where data are co-generated by farmers, machinery, software, satellite systems, service providers, and public information sources. Even where a farmer is described as an owner, practical control may remain limited if the data cannot be exported in a usable format, if access depends on continued subscription, if downstream uses are broadly authorized, or if withdrawal is technically ineffective. Policy analysis should therefore evaluate access rights, usage authority, portability, transparency, competition, contractual dependence, and institutional trust together rather than assuming that a single ownership rule can resolve agricultural data-governance problems [12].

The proposed approach treats farmer protection as a multidimensional assessment covering autonomy, agency, bargaining power, consent, transparency, data stewardship, value distribution, portability, and contestability. Farmer autonomy concerns the existence of meaningful alternatives and the practical ability to leave or change services. Farmer agency concerns the ability to influence governance decisions. Bargaining power concerns whether farmers can negotiate individually or collectively rather than merely accept standardized terms. Data stewardship concerns responsibility for quality, documentation, security, and appropriate use. Fair value distribution requires examination of economic and non-economic benefits, including improved services, returned knowledge, reduced risk, and recognition of farmer contribution. Accessible dispute-resolution pathways are also necessary where data are inaccurate, inaccessible,

misused, or valued in contested ways. These components can strengthen policy analysis, but their inclusion does not by itself establish legal compliance or guarantee that farmers will be protected in practice.

Privacy, Competition, and Platform Power

Privacy risks in agricultural data markets extend beyond information conventionally understood as directly identifying an individual. Farm data may reveal household routines, labour patterns, financial conditions, production strategies, machinery movements, land-use decisions, or commercially sensitive practices when combined with location, ownership, remote-sensing, or supply-chain information. Governance should therefore examine the complete data lifecycle, including collection, linkage, inference, storage, access, onward transfer, retention, security, and deletion. Clear agreements, understandable explanations, purpose limitation, access controls, data minimization, cybersecurity measures, and incident-response arrangements may reduce risk, but they cannot eliminate every possibility of misuse, breach, or harmful inference [13].

Platform power arises when a provider can determine the terms of participation, permissible data uses, technical interfaces, visibility of information, service integration, and conditions of exit. Contractual statements that farmers retain ownership may coexist with broad provider permissions, extensive analytic reuse, limited transparency, and weak practical control. The policy question is therefore not only who is described as the owner, but who can operationally decide how data are processed, combined, commercialized, transferred, or retained. This distinction is particularly important where standardized platform terms create an appearance of control while the underlying infrastructure remains inaccessible to farmers and difficult to scrutinize [14].

Competition concerns may also arise at the ecosystem level rather than through the conduct of a single isolated company. Large agricultural platforms can cooperate through technical partnerships, bundled services, complementary datasets, shared infrastructure, or cross-platform alliances while continuing to compete in particular service markets. Such arrangements may facilitate innovation and interoperability, but they may also reinforce concentration, establish shared barriers to entry, and increase farmer dependence on a limited group of interconnected providers. Policy analysis should therefore examine market concentration, ecosystem closure, data advantages, network effects, vendor lock-in, switching costs, and the availability of credible alternatives without presuming that collaboration is inherently harmful or that concentration automatically establishes unfair conduct [15].

Intellectual-property arrangements, trade secrecy, database control, software licensing, technical protection, and contractual restrictions can further shape access to agricultural data and analytics. These mechanisms may support investment and innovation, yet they may also limit portability, constrain complementary services, obscure data valuation, or reinforce bargaining asymmetries. Privacy safeguards alone cannot correct these structural effects, and competition-oriented measures alone cannot resolve privacy, consent, or farmer-agency concerns. Effective policy analysis therefore requires integrated evaluation of data-intermediary power, information asymmetry, auditability, traceability, accountability, platform dependency, and market access. The proposed framework can identify where these concerns interact, but it does not determine intellectual-property entitlement, establish unlawful conduct, or certify that a market arrangement is fair [16].

Interoperability and Fair Data Exchange

Fair agricultural data exchange requires both trusted governance conditions and interoperable, documented data structures that preserve meaning across systems [17, 18]. Data-sharing arrangements should specify the actors involved, the purposes of exchange, the categories of data covered, the conditions of access, the permitted downstream uses, and the responsibilities attached to data quality, security, provenance, and correction. Technical transfer without understandable rights or trustworthy relationships may expose farmers to unanticipated uses, whereas governance commitments without usable formats may leave data practically inaccessible. Fair exchange therefore depends on the

interaction of institutional trust, transparent access rules, privacy safeguards, data stewardship, standardization, and visible reciprocal benefit.

Interoperability should be evaluated across technical, semantic, organizational, and governance dimensions. Technical interoperability concerns whether systems can connect and transfer data. Semantic interoperability concerns whether transferred data retain consistent meanings, units, classifications, and contextual information. Organizational interoperability concerns whether participating actors possess compatible processes and responsibilities. Governance interoperability concerns whether access permissions, usage controls, accountability arrangements, and sovereignty expectations remain intelligible across institutional boundaries. Agricultural data-space architectures may help connect these dimensions by coupling exchange mechanisms with decentralized control, but architectural compatibility does not independently establish fair participation or protect farmers from unequal contractual and market relationships [19].

Cross-platform exchange is especially important where farm histories, machine records, advisory outputs, remote-sensing information, and production data are distributed among several services. Effective exchange may require compatible application interfaces, common data models, metadata vocabularies, identity management, trust services, security protocols, provenance records, and mechanisms for transferring permissions and usage conditions. Alignment among agricultural interoperability architectures may reduce avoidable fragmentation and support complementary services, but implementation must also consider performance, documentation, nondiscriminatory access, and the capacity of farmers and advisors to use transferred data [20]. **Figure 1** illustrates the policy logic connecting agricultural data market actors, farm data flows, ownership and access issues, privacy and competition risks, interoperability requirements, and fair data exchange safeguards.

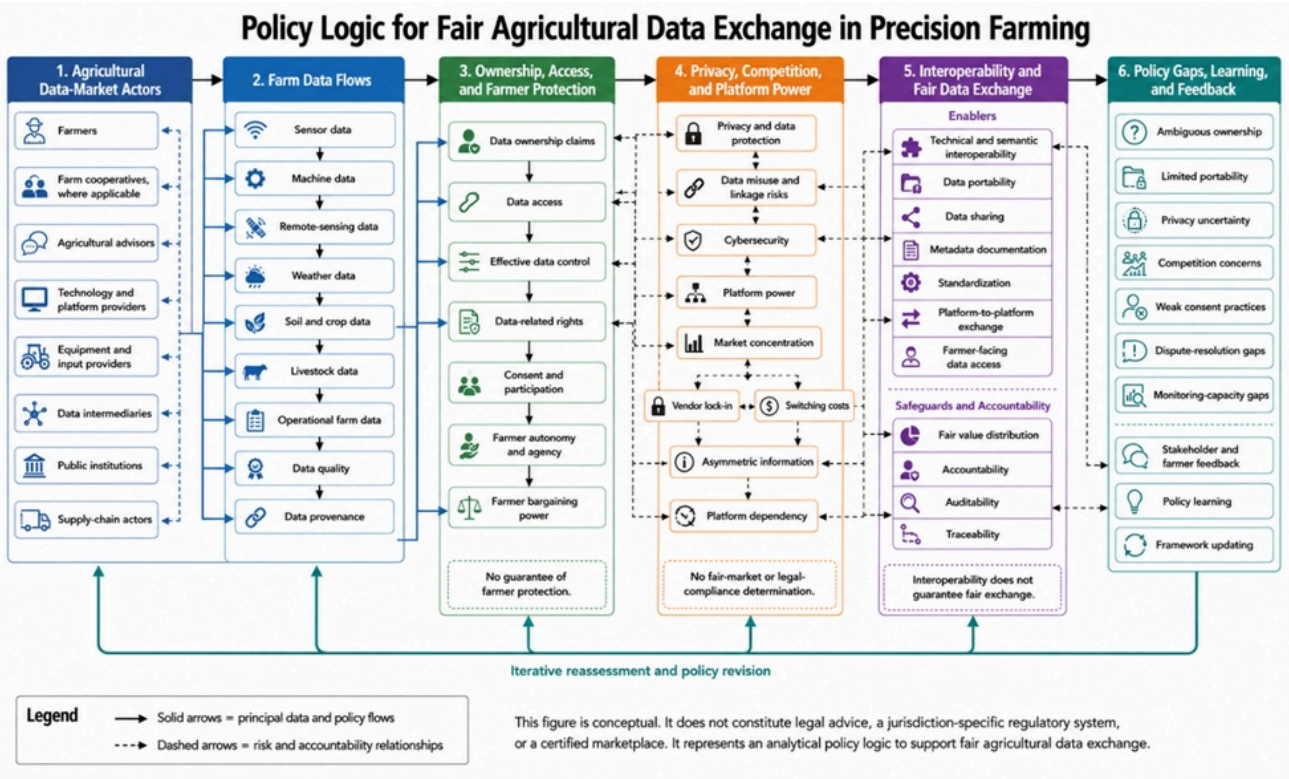


Figure 1. Policy Logic for Fair Agricultural Data Exchange in Precision Farming

Alt-text description:

A conceptual policy logic diagram showing agricultural data market actors connected by farm data flows, ownership and

access issues, privacy risks, competition and platform power concerns, interoperability requirements, fair data exchange safeguards, farmer protection, and feedback loops.

Even where interoperable exchange is technically possible, fairness depends on data quality, provenance, metadata completeness, usable farmer-facing access, and mechanisms for accountability and dispute resolution. Machine data should remain interpretable beyond the original equipment environment, while remote-sensing data should be accompanied by information on spatial resolution, timing, processing, uncertainty, and linkage risks. Farmers should be able to retrieve usable records without losing contextual information, and data recipients should be able to identify origins, transformations, limitations, and applicable use conditions. Portability, interoperability, transparency, and standardization can reduce friction and dependency, but none guarantees equitable value distribution or responsible downstream use.

Table 1 summarises ownership, access, privacy, competition, interoperability, and fair data exchange requirements for agricultural data markets in precision farming.

Table 1. Policy Requirements for Agricultural Data Markets in Precision Farming: Data Ownership, Access, Control, Portability, Farmer Protection, Privacy, Competition, Platform Power, Interoperability, Data Quality, Data Provenance, Fair Data Exchange, Accountability, and Claim Boundaries

Policy component	Core policy question	Required evidence or condition	Policy function	Potential output	Risk of overinterpretation	Governance need
Farm data definition	Which farm-related data are included, and how were they generated?	Inventory of sensor, machine, soil, crop, livestock, weather, remote-sensing and operational data	Define the governed data domain	Context-specific farm-data map	Treating all agricultural data as legally or economically identical	Data classification and documentation
Data ownership	What authority is being claimed through ownership terminology?	Generation context, contractual language, co-generation relationships and relevant institutional context	Clarify ambiguous ownership assertions	Ownership-claim register	Assuming ownership provides complete protection	Separation of ownership from access, control and use
Data access	Who can obtain which data, for which purpose and under what conditions?	Access rules, interfaces, authorization processes and third-party permissions	Identify access asymmetries	Role-based access matrix	Equating nominal access with usable access	Transparent and reviewable access conditions
Data control	Who can authorize reuse,	Technical controls,	Assess effective	Control-rights profile	Assuming formal ownership equals	Usage controls and conflict-

	transfer, retention, linkage or deletion?	operational practices and contractual authority	decision-making power		practical control	management procedures
Data rights	Which access, use, objection, correction, portability and participation interests are relevant?	Context-specific legal and institutional assessment	Distinguish different data-related interests	Data-rights taxonomy	Presenting conceptual categories as legally determinative	Jurisdiction-specific assessment where applicable
Data portability	Can farmers retrieve and move complete, usable and contextualized data?	Machine-readable exports, metadata, timing, cost and continuity arrangements	Reduce avoidable switching barriers	Portability-readiness result	Treating a downloadable file as meaningful portability	Migration support and portability testing
Consent and participation	Are data uses understandable, revisable and open to meaningful influence?	Plain-language information, participation processes and withdrawal routes	Assess legitimacy and farmer involvement	Consent and participation protocol	Treating a one-time acceptance as continuing informed participation	Layered communication and stakeholder engagement
Farmer autonomy and agency	Can farmers make meaningful choices and influence governance decisions?	Service alternatives, dependencies, representation and decision pathways	Identify practical constraints on choice and influence	Farmer-autonomy and agency profile	Assuming formal choice or consultation creates genuine influence	Representative and deliberative governance
Bargaining power	Can farmers negotiate individually or collectively over data terms and benefits?	Market alternatives, contract practices, cooperative capacity and independent advice	Identify negotiating asymmetries	Bargaining-power assessment	Assuming all farmers possess comparable leverage	Collective representation and accessible advice
Data stewardship	Who maintains data quality, security, documentation and appropriate use?	Stewardship mandates, resources, competencies and oversight	Allocate operational responsibilities	Stewardship charter	Treating a stewardship label as proof of trustworthy conduct	Competent, resourced and accountable stewardship

Data quality	Are data accurate, complete, timely, representative and fit for their intended use?	Quality criteria, validation records and responsibility allocation	Reduce decision error and disputes	Data-quality statement	Assuming source reputation establishes quality	Shared quality responsibilities
Data provenance and metadata	Can origin, transformations, context, units, limitations and use conditions be reconstructed?	Persistent identifiers, lineage records and metadata documentation	Support traceability, interpretation and accountability	Provenance and metadata record	Assuming documented lineage proves accuracy or legitimacy	Common metadata and provenance practices
Fair data exchange	Are purposes, benefits, risks and burdens transparent and proportionate?	Contribution mapping, use purposes, benefit allocation and stakeholder input	Connect exchange mechanics with substantive fairness	Fair-exchange assessment	Equating exchange, payment or interoperability with fairness	Reviewable exchange and benefit-sharing arrangements
Accountability, auditability and traceability	Can access, use, transformation and decisions be independently examined and challenged?	Logs, responsibility maps, evidence retention and complaint routes	Enable verification and correction	Accountability pathway and audit record	Assuming records alone ensure responsible conduct	Independent review and corrective procedures
No legal-compliance claim boundary	Has the arrangement undergone competent jurisdiction-specific assessment?	Applicable facts, law, contracts and institutional conditions	Prevent inappropriate reliance on the framework as legal advice	Explicit legal-boundary statement	Treating the framework as a compliance checklist	Independent legal and institutional assessment
No farmer-protection guarantee boundary	Have safeguards been implemented and evaluated through farmer-centred evidence?	Monitoring results, complaints, participation and outcome evidence	Distinguish proposed safeguards from demonstrated protection	Protection-limitation statement	Presenting framework inclusion as proof of protection	Continuing monitoring and corrective action
No fair-market or fair-	Have market and	Competition evidence,	Prevent premature	Fairness-limitation	Treating compatibility or	Market monitoring and

exchange guarantee boundary	distributional outcomes been empirically assessed?	value- distribution evidence and stakeholder outcomes	fairness claims	statement	transparency as proof of fairness	independent evaluation
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Policy Gaps in Agricultural Data Markets

Agricultural data-market policy remains incomplete where responsibilities, acceptable uses, privacy expectations, value distribution, and accountability are insufficiently specified. Ambiguous ownership terminology can coexist with unclear access and control, while generalized references to innovation may obscure conflicts among farmers, providers, intermediaries, and public institutions. Ethical questions also arise when decision-support systems, automated recommendations, or data-derived inferences affect production without transparent responsibility for errors, exclusions, or unintended consequences. These gaps demonstrate that data-market governance must address values, responsibilities, and institutional relationships rather than merely technical functionality [21].

Risk perceptions are unlikely to be uniform across stakeholder groups. Farmers may emphasize loss of control, privacy, dependency, or unfair value capture, while technology providers may emphasize innovation, system security, or the need to aggregate data. Public institutions may focus on public value, infrastructure, rural development, or monitoring capacity, whereas advisors and cooperatives may be concerned with access, trust, and their changing intermediary roles. Divergent interpretations can make apparently neutral concepts—such as data sharing, consent, ownership, or public interest—politically contested. Deliberative policy assessment is therefore needed to identify whose risk definitions are reflected in governance arrangements and whose concerns remain marginalized [22].

Additional gaps arise from unequal digital capability, infrastructure, literacy, and institutional support. Portability may exist formally but remain unusable to farmers without technical assistance. Consent procedures may be available but incomprehensible. Interoperability standards may be developed but inaccessible to smaller providers. Monitoring responsibilities may be assigned to organizations lacking staff, data access, expertise, or authority. A people-centred approach to agricultural digitalization must therefore address skills, advisory capacity, rural connectivity, inclusion, workload, and distributional consequences alongside production and innovation objectives [23].

Existing agricultural data-sharing arrangements may also leave sector-specific gaps in terminology, portability, interoperability, co-generated data, implementation, accountability, and enforcement capacity. Voluntary governance mechanisms can promote trust and common expectations, but their effectiveness may be limited where participation is uneven, terminology is ambiguous, incentives are weak, or no credible monitoring process exists. Horizontal data-governance measures may similarly require agricultural interpretation because farm data are generated through complex relationships among land, machinery, software, services, biological processes, and supply-chain activities. These observations support policy experimentation and institutional assessment but do not establish that a particular governance model is legally sufficient, universally transferable, or implementation-ready [24].

Proposed Policy Framework

The proposed policy framework is organized as an iterative sequence rather than a fixed compliance checklist. It begins by defining the agricultural data market under examination and then moves through actor mapping, data-flow analysis, rights and risk assessment, safeguard selection, implementation review, monitoring, and updating. This sequence reflects responsible-innovation principles because governance decisions should anticipate potential consequences, include affected actors, question embedded assumptions, and respond to evidence generated during implementation. Each stage produces an analytical output that informs later stages, while monitoring and stakeholder feedback can reopen earlier decisions when market structures, data uses, or technologies change [25].

The first stage defines the agricultural data-market boundary by identifying the precision-farming context, relevant services, data categories, geographic and institutional scope, and relationships among marketplaces, platforms, devices, intermediaries, cooperatives, advisors, supply-chain actors, and public institutions. The second stage maps stakeholders and distinguishes data generators, rights holders, service users, infrastructure providers, decision makers, downstream recipients, and affected communities. Farmers should be treated as rights holders and governance participants rather than only as technology users, customers, or sources of data. Their involvement should extend to defining legitimate purposes, acceptable risks, benefit expectations, dispute pathways, and framework revisions [26].

The third stage maps data collection, storage, transformation, inference, access, transfer, retention, and deletion. It should identify where sensor, machine, crop, soil, weather, remote-sensing, livestock, and operational data are combined and where provenance or quality information may be lost. The fourth and fifth stages assess ownership, access, control, portability, consent, farmer autonomy, farmer agency, bargaining power, value distribution, and dispute resolution. Implementation must also account for agricultural advisors, knowledge brokers, cooperatives, and other intermediaries because they can translate technical information, facilitate participation, mediate trust, and influence whether farmers can exercise formal data rights in practice [27].

The sixth through ninth stages examine privacy, data protection, cybersecurity, competition, platform power, interoperability, and fair exchange. Privacy assessment considers linkage, inference, retention, onward use, and misuse risks. Competition assessment considers concentration, gatekeeping, data advantages, switching costs, lock-in, information asymmetry, and intermediary power. Interoperability assessment covers technical, semantic, organizational, and governance compatibility. Fair-exchange assessment considers purpose clarity, data quality, provenance, reciprocity, value distribution, farmer-facing access, accountability, auditability, and traceability. Stakeholder-specific values may differ, but control, privacy, trust, autonomy, justice, interoperability, and avoidance of dependency provide important criteria for evaluating agricultural data-space design [28].

The final stages identify unresolved policy gaps, select context-sensitive governance safeguards, review implementation capacity and unintended consequences, establish monitoring and accountability arrangements, collect stakeholder feedback, and update the framework. Possible safeguards include improved transparency, access documentation, consent revision, portability testing, interoperability assessment, stewardship arrangements, dispute pathways, independent review, market monitoring, and farmer participation. Their suitability requires empirical, institutional, technical, economic, and legal assessment where relevant. The framework does not establish legal compliance, guarantee farmer protection, certify fair competition, or demonstrate implementation readiness. **Table 2** presents the proposed policy framework for agricultural data markets in precision farming. **Figure 2** presents the proposed policy framework for agricultural data markets in precision farming, integrating ownership, access, farmer protection, privacy, competition, interoperability, fair exchange, policy-gap identification, governance safeguards, implementation review, and feedback updating.

Table 2. Proposed Policy Framework for Agricultural Data Markets in Precision Farming: Market Boundary Definition, Stakeholder Mapping, Data Flows, Ownership and Access, Farmer Protection, Privacy, Competition, Platform Power, Interoperability, Fair Exchange, Policy Gaps, Governance Safeguards, Monitoring, Feedback, and Claim Boundaries

Framework stage	Core purpose	Required input	Policy function	Potential output	Validation or assessment need	Failure
Agricultural data market boundary definition	Specify the market relationships, services, technologies and data uses	Precision-farming use cases, geographic scope, platforms,	Prevent an overbroad or technically vague assessment	Agricultural data-market boundary statement	Stakeholder and sector-expert review	Omitted complem service depende affected

	under examination	services, devices and institutional context				
Stakeholder and actor mapping	Identify parties that generate, control, use, mediate or are affected by data	Farmer, cooperative, advisor, technology, equipment, input, platform, intermediary, public and supply-chain actors	Make roles, interests and power visible	Actor-and-role map	Representation assessment, especially for less powerful groups	Treat stakeholder categories as homogeneous
Data-flow mapping	Trace collection, storage, transformation, inference, sharing, retention and deletion	System architecture, operational records, interfaces and contractual descriptions	Reveal hidden transfers and technical dependencies	Data-flow and lineage map	Technical verification and participant confirmation	Document flows differently from actual processes
Data-quality and provenance review	Examine accuracy, completeness, context, lineage and metadata	Quality criteria, source records, transformation history and metadata	Determine whether data remain interpretable and fit for use	Quality and provenance profile	Domain-specific validation	Poor-quality data are decontextualized as unreliable
Ownership and access assessment	Separate ownership assertions from access, use and control capabilities	Contracts, co-generation context, technical controls and institutional assessment	Clarify competing claims and operational authority	Ownership-access-control matrix	Context-specific legal and stakeholder review	Governance reduced ownership
Data-control and rights assessment	Identify authority over reuse, transfer, retention, correction and deletion	Permissions, platform rules, usage controls and rights claims	Examine effective decision-making power	Control-and-rights profile	Technical and institutional verification	Stated control differs from operational control
Farmer-protection assessment	Evaluate autonomy, agency, consent, bargaining,	Farmer-facing information, alternatives, contracts and	Determine whether safeguards are meaningful in practice	Farmer-protection risk profile	Diverse farmer participation and usability testing	Design around hypothesized average

	transparency and contestability	complaint routes				
Data-stewardship and valuation assessment	Clarify responsibility for quality, security, documentation and benefit allocation	Stewardship mandates, data uses, contribution evidence and valuation assumptions	Allocate responsibilities and expose value-capture logic	Stewardship charter and value-distribution map	Competence, conflict-of-interest and distributional review	Steward symbol valuation opaque
Privacy risk assessment	Identify personal, household, linkable and commercially sensitive data risks	Data inventory, purposes, linkage potential, retention and security arrangements	Structure lifecycle privacy safeguards	Privacy-risk register	Specialist and context-specific assessment	Farm data assumed automa non-per
Cybersecurity assessment where relevant	Examine unauthorized access, manipulation and operational disruption risks	Threat model, device and platform architecture, controls and recovery capacity	Connect data governance with system resilience	Cybersecurity-risk profile	Technical testing and incident preparedness review	Security treated one-time certific exerc
Competition and platform-power assessment	Examine concentration, gatekeeping, access restrictions and ecosystem power	Market relationships, interfaces, pricing, data advantages and alliances	Identify structural risks to choice, entry and bargaining	Platform-power and dependency profile	Economic, technical and institutional assessment	Concentrated treated autom eviden abus
Lock-in and switching assessment	Determine whether participants can realistically change providers	Portability, interoperability, migration cost, downtime and contractual conditions	Assess practical dependency	Exit and switching-risk profile	Migration testing and farmer-centred evaluation	Form portability unusa transi
Interoperability assessment	Evaluate technical, semantic, organizational and governance compatibility	Standards, APIs, metadata, identity, permissions and trust mechanisms	Determine whether data can move and remain usable	Interoperability-readiness profile	Conformance and practical exchange testing	Pap compli witho functio excha

Fair data exchange assessment	Examine purpose, reciprocity, quality, transparency, value and burden distribution	Exchange terms, data contribution, use purposes, risks and benefits	Connect data transfer with substantive fairness	Fair-exchange assessment	Distributional and farmer-centred evaluation	Exchange volume payments treated as a part of fair
Policy-gap identification	Compare existing arrangements with required capabilities and protections	Results of all preceding assessments	Prioritize unresolved governance problems	Policy-gap register	Multidisciplinary and stakeholder review	Gaps are identified without a clear priority or affected
Governance-safeguard selection	Match proposed safeguards to identified mechanisms and responsible actors	Gap register, feasibility evidence, institutional context and resources	Avoid generic or one-size-fits-all interventions	Context-sensitive safeguard portfolio	Proportionality, compatibility and stakeholder assessment	Symbolic safeguard conflict requires
Implementation-risk review	Assess capacity, cost, exclusion, incentives and unintended effects	Skills, funding, infrastructure, organizational readiness and stakeholder capacity	Test practical feasibility	Implementation-risk register	Context-specific institutional assessment	Adoption resources expertise particip
Monitoring and accountability planning	Define indicators, evidence access, responsibilities and escalation	Objectives, logs, audit evidence, complaints and responsible bodies	Make governance observable and correctable	Monitoring and accountability plan	Independent review and indicator validation	Monitoring without a clear or corrective action
Stakeholder feedback	Incorporate experience from farmers and other affected actors	Participatory forums, surveys, complaints, advisory networks and cooperative input	Detect emerging harms, dependencies and misunderstandings	Documented feedback-and-response record	Inclusiveness and representativeness assessment	Consultation occurs via influence
Framework updating	Revise definitions, assessments,	Monitoring findings, incidents,	Keep the framework adaptive	Versioned policy-	Transparent rationale and	Stat arrangements beco

	safeguards and priorities	market change and stakeholder feedback		framework update	renewed assessment	obsole captu
No legal-compliance claim boundary	Prevent use as a substitute for jurisdiction-specific legal assessment	Scope statement and relevant institutional context	Preserve the framework's analytical status	Legal-boundary declaration	Independent assessment where application requires it	Framew repres legal ac
No farmer-protection guarantee boundary	Distinguish proposed safeguards from demonstrated outcomes	Farmer outcomes, complaints, participation and monitoring evidence	Prevent premature protection claims	Protection-boundary declaration	Empirical farmer-centred evaluation	Safeguar present proof protec
No fair-market guarantee boundary	Distinguish policy analysis from proof of competitive or distributive fairness	Market evidence, value distribution and implementation outcomes	Limit conclusions to structured policy assessment	Fair-market boundary declaration	Economic and institutional evaluation	Conce coherer mistake market fa

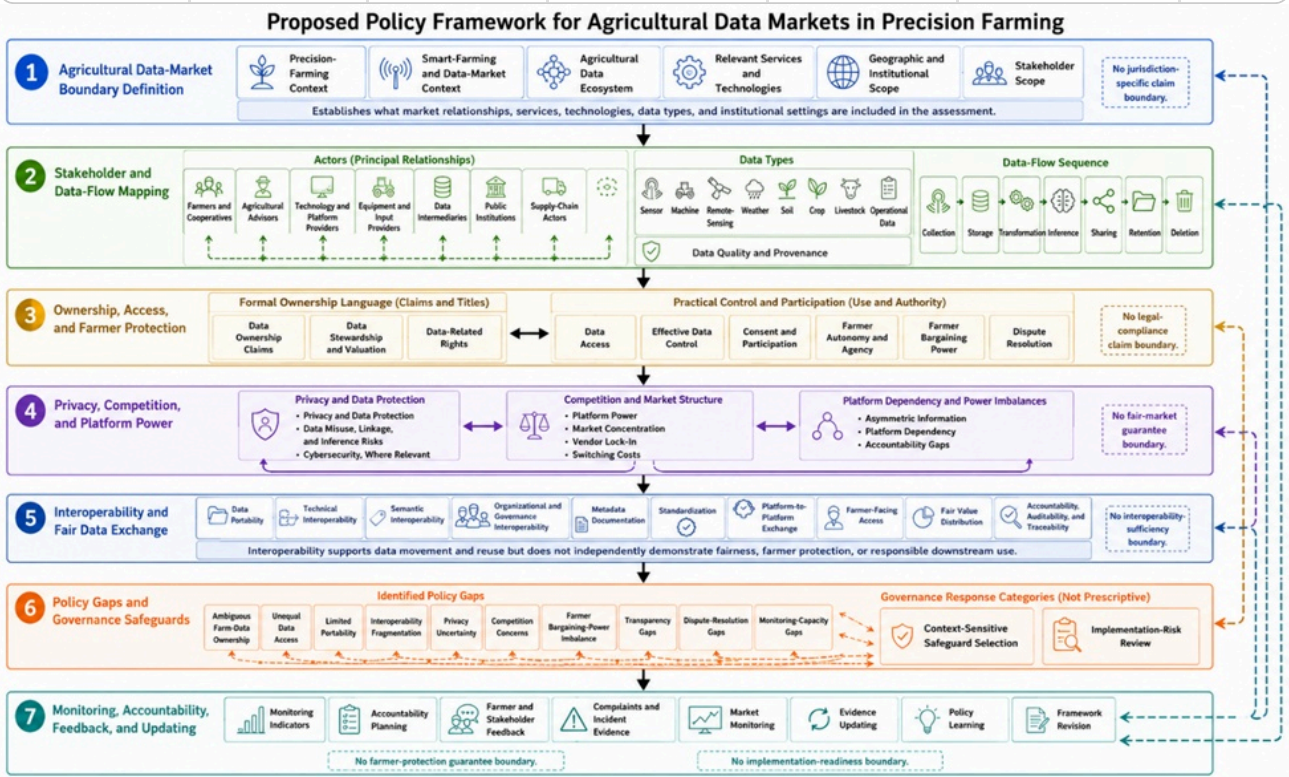


Figure 2. Proposed Policy Framework for Agricultural Data Markets in Precision Farming

Alt-text description:
A conceptual policy framework showing agricultural data market boundaries, stakeholder mapping, data flows, ownership

and access, farmer protection, privacy, competition, platform power, interoperability, fair data exchange, policy gaps, safeguards, implementation risks, monitoring, accountability, and feedback loops.

Implementation Risks and Recommendations

Implementation should begin with institutional and stakeholder-capacity assessment rather than immediate assumption that all actors can perform the responsibilities allocated to them. Farmers and cooperatives may require technical, contractual, and data-literacy support to evaluate access conditions, exercise portability, understand data uses, and participate in governance. Agricultural advisors may need new competencies in platform comparison, data interpretation, privacy communication, and dispute support. Technology providers, equipment suppliers, platforms, and intermediaries should be able to document data flows, interfaces, metadata, security responsibilities, and downstream-use conditions in forms that are understandable to non-specialists. Public institutions and research organizations should assess whether they possess sufficient expertise, authority, resources, and evidence access to monitor implementation without displacing farmer participation or creating excessive administrative burdens [27].

Implementation should also be staged, monitored, and open to correction. Portability should be tested through realistic migration exercises rather than inferred from the existence of an export function. Interoperability should be evaluated through practical exchange across different platforms and devices. Privacy safeguards should be assessed against actual linkage and inference risks, while competition monitoring should examine ecosystem relationships, concentration, exclusionary interfaces, switching barriers, and the distribution of data-enabled value. Accessible dispute pathways, transparent responsibility allocation, audit records, provenance information, incident response, and independent review can support accountability, but their effectiveness depends on institutional capacity and corrective authority. Agricultural data-sharing policy should therefore be revised in response to implementation evidence rather than treated as complete when principles or voluntary commitments are first adopted [24].

The recommendations advanced here are research-informed policy considerations rather than legal advice, regulatory prescriptions, procurement guidance, operational market rules, or mandatory contractual terms. Policymakers and public institutions can use the framework to identify evidence gaps and coordinate stakeholder discussion. Farmer organizations and cooperatives can use it to structure questions about control, portability, benefit, dependency, and dispute resolution. Providers and intermediaries can use it to examine whether their architectures, disclosures, interfaces, and governance procedures support meaningful participation and accountability. Researchers can test individual stages, indicators, safeguards, and distributional outcomes across farm types and institutional settings. Continued farmer feedback should remain central because values such as privacy, control, trust, autonomy, interoperability, and justice may be understood differently across stakeholder groups and may change as data markets evolve [28].

Conclusion

This article proposes an integrated policy framework for agricultural data markets in precision farming that connects market-boundary definition, stakeholder and data-flow mapping, ownership and access, farmer protection, privacy, competition, platform power, interoperability, fair data exchange, policy-gap identification, governance safeguards, implementation risks, monitoring, accountability, and feedback updating. Its central argument is that agricultural data markets should not be evaluated through innovation, efficiency, or monetization potential alone. Responsible policy-oriented analysis must examine effective data control, meaningful participation, privacy and security risks, bargaining and platform power, portability, interoperability, data quality, provenance, contestability, and fair distribution of benefits and burdens. The framework offers a structured basis for identifying governance questions and research priorities while maintaining clear boundaries: it does not establish legal compliance, guarantee farmer protection, certify fair competition or fair exchange, or demonstrate implementation readiness. Its usefulness therefore depends on context-specific evidence, stakeholder participation, institutional capacity, monitoring, and continuing revision.

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