agronomy

Article

An IDS-Compliant Agricultural Data Space Tailored to the Italian Context

Francesco Camaccioli [1], Manlio Bacco [2], Gianluca Brunori [3], Federica Casarosa [4], Stefano Chessa [5] and Alexander Kocian [3,5,*]

[1] Department of Information Engineering, University of Pisa, 56122 Pisa, Italy
[2] European Commission, Joint Research Centre (JRC), 21027 Ispra, Italy; manlio.bacco@ec.europa.eu
[3] Department of Agriculture, Food and Environment, University of Pisa, 56124 Pisa, Italy; gianluca.brunori@unipi.it
[4] Institute of Law, Politics and Development, Sant'Anna School of Advanced Studies, 56127 Pisa, Italy; federica.casarosa@santannapisa.it
[5] Department of Computer Science, University of Pisa, 56127 Pisa, Italy; stefano.chessa@unipi.it
* Correspondence: alexander.kocian@unipi.it

Abstract

The digital transformation of agriculture has generated vast heterogeneous datasets from sensors, machinery, and administrative systems; however, interoperability and data sovereignty remain critical challenges. This study presents an IDS-compliant Agricultural Data Space tailored to the Italian context, integrating regulatory frameworks (General Data Protection Regulation, Data Governance Act and Data Act) with the International Data Spaces (IDS) Reference Architecture Model. The study addresses key barriers to data sharing, including technical fragmentation, governance gaps, and economic incentives, by mapping Italian agricultural data flows onto the five-layer IDS model. Policy-based usage control is implemented through machine-enforceable Open Digital Rights Language policies, enabling farmer-centric data sovereignty. Three use cases, namely administrative Common Agricultural Policy (CAP) declarations, machine-generated data portability, and agri-food supply-chain traceability, demonstrate how structured and interoperable data exchange can reduce redundancy, mitigate vendor lock-in, and support sustainable agri-food systems. The findings highlight the feasibility of IDS-driven solutions in real-world agricultural ecosystems, emphasizing the need for sector-specific policy templates and scalable governance mechanisms. This work contributes to the development of the Common European Agricultural Data Space by bridging institutional, technical, and regulatory gaps.

Keywords: data governance; data economy; data sovereignty; usage policy; data regulation; data taxonomy; international data space; agri-food

Academic Editor: Paul Kwan

Received: 7 April 2026
Revised: 10 May 2026
Accepted: 15 May 2026
Published: 17 May 2026

1. Introduction

The increasing digitalization of agriculture, driven by advances in sensing technologies, Internet of Things (IoT) devices, precision farming systems, and data-driven decision support systems, has led to the generation of large volumes of heterogeneous agricultural data. These data originate from multiple sources, including on-field sensors, agricultural machinery, satellite imagery, and farm management platforms. Effectively leveraging such data is widely recognized as a key enabler for improving productivity, sustainability, and resource efficiency in modern agriculture [1,2]. However, several challenges hinder effective

 https://doi.org/10.3390/agronomy16100990

agricultural data sharing and reuse. At the technical level, the most relevant issues concern access and interoperability between heterogeneous systems and semantic consistency across datasets. From the organizational and legal perspectives, uncertainties regarding data control, lawful reuse, and data sovereignty continue to limit collaboration among stakeholders. These challenges are further exacerbated by the widespread use of proprietary digital platforms, which create isolated data silos and vendor lock-in effects [2,3].

The aforementioned challenges, moreover, are not peculiar to agriculture but are common to many data-driven sectors. In this context, the European Union has introduced the concept of Common European Data Spaces (CEDS) https://digital-strategy.ec.europa.eu/en/policies/data-spaces (accessed on 14 May 2026), aiming to foster secure, interoperable, and sovereign data sharing across stakeholders [3]. Within this vision, the Common European Agricultural Data Space (CEADS) was proposed to support data-driven innovation and interoperability in the agricultural sector [4]. However, despite ongoing European initiatives, the practical realization of agricultural data spaces remains limited. Agriculture presents several sector-specific difficulties, including heterogeneous farming systems, fragmented administrative infrastructures, distributed data-generation environments, and uneven levels of technological adoption [2,5]. Furthermore, agricultural datasets frequently combine personal and non-personal information, requiring compliance with multiple regulatory frameworks including the General Data Protection Regulation (GDPR), the Data Governance Act (DGA), and the Data Act.

One of the primary barriers to the implementation of agricultural data spaces is the lack of an integrated framework capable of integrating interoperability, data sovereignty, and regulatory compliance within operational agricultural ecosystems. Existing initiatives and research efforts often address these dimensions separately. Some works focus on semantic interoperability and technical integration, while others emphasize governance models, business ecosystems, or legal aspects of data sharing. As a consequence, limited attention has been devoted to operational frameworks capable of integrating heterogeneous agricultural data flows, policy-based usage control, and regulatory requirements into a coherent architecture applicable to real-world agricultural scenarios. On top of the technical challenges, farmers and other stakeholders are often reluctant to share data due to uncertainties regarding data control, potential misuse, and unclear value propositions [4]. Turning to economic factors, unlike in sectors such as healthcare, where strong regulatory frameworks and public interest drive data sharing, the incentives for participating in agricultural data spaces are less defined [3,5]. In particular, small and medium-sized farms, representing the majority of agricultural actors in Europe, may lack both the resources and motivation to engage in data-sharing initiatives [4,6,7].

Among the available European initiatives, the International Data Spaces (IDS) Reference Architecture Model provides a structured framework for trusted and sovereign data exchange through interoperable connectors, semantic interoperability models, federated governance mechanisms, and machine-enforceable usage policies [8]. In particular, IDS enables policy-based control over data access and reuse through Open Digital Rights Language (ODRL) policies, allowing data providers to define conditions for data processing, sharing, and reuse. These characteristics make IDS particularly relevant for agriculture, where farmers and agri-food stakeholders require fine-grained control over operational and commercially sensitive data while maintaining interoperability across heterogeneous systems.

This paper addresses the aforementioned gap by proposing an IDS-compliant agricultural data space framework tailored to the Italian context. Italy represents a particularly relevant case study due to the coexistence of heterogeneous levels of digitalization, fragmented administrative procedures related to the Common Agricultural Policy (CAP), and proprietary agricultural technology ecosystems. The work focuses on three interconnected research problems: (i) interoperability between heterogeneous agricultural and administrative systems, (ii) enforcement of farmer-centric data sovereignty through policy-based usage control, and (iii) alignment between technical data-sharing architectures and the European regulatory framework, including General Data Protection Regulation, the Data Governance Act, and the Data Act.

Despite recent advances in agricultural data-space research, existing studies mainly address interoperability, governance, or regulatory compliance separately, while limited attention has been devoted to integrated frameworks capable of combining these dimensions within operational agricultural ecosystems. In particular, there are limited studies mapping operational agricultural administrative and operational data flows onto IDS-compliant architectures while simultaneously considering the requirements introduced by the European regulatory framework.

To address this gap, this study provides a high-level and structured mapping between the European data legislative framework and an IDS-compliant architecture, proposing a unified regulatory–technical interpretation tailored to agricultural data-sharing ecosystems. The work analyzes institutional and technical agricultural data flows in the Italian context, including administrative processes managed through the Agency for Agricultural Subsidies (*Agenzia per l'Erogazione in Agricoltura*—AGEA), the National Agricultural Information System (*Sistema Informativo Agricolo Nazionale*—SIAN), and machine-generated agricultural data originating from digital farming technologies. These heterogeneous flows are mapped onto the layers of the IDS Reference Architecture Model (IDS-RAM) [8], enabling a structured analysis of interoperability and governance requirements for agricultural data spaces. Another contribution of the study is the integration of the legal dimension into technical architecture through a privacy-by-design approach. In particular, the work discusses how obligations and requirements introduced by the Data Act can be translated into machine-enforceable Open Digital Rights Language (ODRL) policies within IDS-based infrastructures. This approach illustrates how regulatory safeguards can be internalized into data-space architectures to support farmer-centric data sovereignty and controlled agricultural data sharing. Finally, the proposed framework is illustrated through representative use cases involving CAP subsidy administration, machine-generated data portability, and agri-food supply-chain traceability.

The remainder of the paper is organized as follows. Section 2 describes the adopted methodology. Section 3 reviews related work on agricultural data spaces, interoperability, and governance. Section 4 introduces the concepts underlying Common European Data Spaces and the IDS Reference Architecture Model. Section 5 discusses the relevant European regulatory framework. Section 6 analyzes agricultural data flows and institutional infrastructures in the Italian context. Section 7 presents the proposed use cases, while Section 8 concludes the paper and discusses future perspectives for interoperable agricultural data spaces.

2. Methodology

This study analyzes the potential impact of new data space technologies on the agricultural sector, focusing on the Italian context. Italy was selected as a representative case study due to the coexistence of small and large farms, heterogeneous levels of digitalization, and complex administrative procedures related to the Common Agricultural Policy (CAP).

The methodology combines a literature review with an analysis of agricultural data flows and institutional infrastructures. Scientific publications indexed in Scopus were reviewed together with European Union reports, policy documents, and technical frameworks related to Common European Data Spaces, International Data Spaces, agricultural interoperability, and data governance.

The collected material was analyzed to identify the main categories of agricultural data, the stakeholders involved in data exchange, and the technical and regulatory challenges associated with interoperability and data sovereignty. Particular attention was devoted to machine-generated agricultural data, administrative procedures related to the Common Agricultural Policy (CAP), and traceability information within agri-food supply chains.

The study adopted a deductive and framework-driven methodology in which agricultural data flows and governance requirements were systematically mapped onto the IDS Reference Architecture Model using predefined interoperability, governance, and regulatory criteria. The analysis followed a qualitative and case-study-oriented approach based on the interpretation of European regulatory frameworks, IDS architectural specifications, and institutional agricultural data flows in the Italian context.

Based on this analysis, three representative use cases were identified to illustrate different levels of complexity and stakeholder interaction within agricultural data spaces. The first use case, administrative data sharing for CAP subsidy declarations, represents a relatively simple scenario involving bilateral data exchange between three primary stakeholders. The second use case, portability of machine-generated agricultural data, introduces a more complex scenario involving multiple interacting actors, including farmers, machinery manufacturers, and digital platform providers. The third use case, traceability and sustainability data exchange within agri-food supply chains, represents a multi-stakeholder ecosystem characterized by distributed governance and heterogeneous interoperability requirements. The results of the literature review and contextual analysis are presented in the following sections.

3. Related Works

The conceptual foundations of agricultural data spaces focus on the transformation of agricultural data into strategic assets for innovation, sustainability, and governance. Wolfert et al. [9] introduce the concept of Data Economy for AgriFood Systems (DE4AFS), highlighting the integration of IoT, AI, digital twins, and analytics to support resilient food systems. Brunori et al. [2] extend this vision by advocating a farm-centered European agri-food data space emphasizing inclusiveness and farmer empowerment. European policy documents such as the EU Data Strategy report [10] position data spaces as essential infrastructures for secure, sovereign, and interoperable data sharing across sectors and borders.

A major research direction concerns interoperability and semantic integration among heterogeneous agricultural systems. Van Eeckhout et al. [11] propose the Agrixel standard, a FAIR-compliant framework supporting interoperable AI-driven agricultural services through ontology-based geographic data structures. Chrysakis et al. [12] investigate the integration of the Agricultural Information Model with IDS semantic models to enable cross-platform interoperability. Ahoa et al. [13] systematically review integration approaches for smart agricultural information systems, identifying organizational and governance challenges. Martinez-Ruedas et al. [14] demonstrate how unified agronomic data spaces based on open data can improve accessibility, harmonization, and interoperability for agricultural analytics and decision support.

Several works focus on the development of operational infrastructures and reference architectures for agricultural data spaces. Datta et al. [5] present a scalable reference architecture within the DIVINE project, integrating heterogeneous agricultural data sources while ensuring data sovereignty and semantic interoperability. Kalatzis et al. [15] explore IoT-enabled infrastructures for agricultural policy monitoring and smart farming analytics. Bacco et al. [16] introduce the METRIQA platform, an agricultural data-space implementation supporting interoperable data exchange and analytics.

Governance, trust, and data sovereignty are central themes in agricultural data-space research. Gil et al. [1] investigate sovereignty-by-design approaches using Value Sensitive Design methodologies, emphasizing farmer control, usage policies, and trusted intermediaries. Serna et al. [17] analyze identity and credential management within Gaia-X-aligned data spaces, identifying interoperability and standardization challenges. Singh et al. [18] provide a comparative security analysis of European data-space architectures including IDS-RAM, Gaia-X, FIWARE, and IHAN, focusing on privacy protection and governance mechanisms. Sullivan et al. [19] further examine barriers to agricultural data sharing, highlighting trust, collaboration, and interoperability as key factors limiting large-scale adoption.

Research on business models and ecosystem development examines how agricultural data spaces generate economic and organizational value. Ottmann et al. [20] analyze the Agri-Gaia project to identify methods for designing scalable and collaborative data-driven business models within federated ecosystems. Their work highlights challenges related to cross-organizational coordination, legal uncertainty, and economic sustainability. Wolfert et al. [9] frame agricultural data as a strategic economic resource capable of enabling new services, digital innovation, and sustainable value chains. These studies underline that federated data spaces provide the infrastructure necessary for collaborative innovation, data monetization, and the emergence of novel agri-food digital ecosystems.

Several studies demonstrate the practical application of agricultural data spaces in specific operational scenarios. Farina et al. [21] propose interoperable traceability mechanisms integrating IoT sensors, blockchain technologies, and data spaces within the METRIQA architecture to improve transparency and logistics in agri-food supply chains. Di Bitonto et al. [22] explore AI-driven applications for food safety, nutrition, and disease prevention supported by FAIR data management and decentralized data-sharing infrastructures. Datta et al. [5] validate their architecture through livestock production benchmarking pilots, while Martinez-Ruedas et al. [14] develop interoperable agronomic data services for olive grove management, demonstrating the scalability and applicability of agricultural data-space technologies. Table 1 synthesizes the literature into three macro-dimensions.

Table 1. Summary of literature research into three macro-dimensions.

Dimension	Main Topics	Representative Works
Strategic & Governance	Data economy, sovereignty, policy, trust	[1,2,9,10,17,18]
Technical & Architectural	Interoperability, semantics, platforms	[5,11–13,15,16]
Application & Business	Traceability, AI, business models, pilots	[14,20–22]

Finally, it is worth pointing out two important European initiatives exploring federated agricultural data spaces, namely *DjustConnect* and *agridata.ch*. The former, developed by Flanders Research Institute for Agriculture, Fisheries and Food, focuses on operational and farmer-centric data exchange through interoperable services, consent management, and trusted governance aligned with International Data Spaces and Gaia-X principles. In contrast, the latter initiative emphasizes national-scale interoperability, administrative simplification, and the "once-only" principle for agricultural data reuse across Swiss institutions and stakeholders. While both initiatives support data sovereignty and secure sharing, DjustConnect primarily operates as a practical marketplace-oriented ecosystem, whereas agridata.ch focuses more strongly on governance coordination and public-sector infrastructure development.

4. Data Spaces: Background and Definitions

In recent years, the concept of data spaces has emerged as a key paradigm for enabling trusted and interoperable data sharing across organizations and sectors, not only from the technical but also from the policy perspective. The approach reflects the increasing recognition that data have become a strategic resource for innovation, economic competitiveness, and public policy.

4.1. The Common European Dataspace (CEDS)

Within the European Union, this vision is articulated through CEDS [23], which aims to create a federated ecosystem that enables secure and efficient data sharing while preserving the sovereignty of data providers. The CEDS initiative was introduced as part of the European Strategy for Data, presented by the European Commission in 2020 [24]. The strategy responds to several structural challenges affecting the European data economy, including fragmentation of data infrastructures, limited interoperability across platforms, and the dominance of large global digital service providers. Rather than establishing a single centralized infrastructure, the CEDS framework promotes the development of multiple sector-specific data spaces that enable stakeholders to exchange data under shared governance principles and common interoperability standards.

Sectoral data spaces are expected to emerge in several domains, for instance, manufacturing, mobility, energy, agriculture, and health. Each domain may develop its own governance structures, semantic models, and operational policies reflecting the specific characteristics of the sector. At the same time, all data spaces must adhere to a common set of guiding principles defined at the European level, including openness, transparency, fairness, interoperability, and respect for data sovereignty. The objective is to enable a European data ecosystem in which organizations can collaborate across institutional and national boundaries while maintaining control over their data assets.

To support the implementation of this vision, the European Commission established the Data Spaces Support Centre (DSSC) https://dssc.eu/ (accessed on 14 May 2026), which coordinates the development of common building blocks and best practices for emerging data spaces. The DSSC contributes to defining reference architectures, interoperability guidelines, and governance models that facilitate compatibility between sectoral initiatives. In this context, the development of practical technical frameworks capable of implementing these principles has become a central requirement for operational data spaces [25].

4.2. The Five-Layer Reference Architecture Model (IDS-RAM)

Although several initiatives have been developed in recent years at the European level, such as IDS, Gaia-X, FIWARE and others [26], the choice fell on one of the first initiatives as it provides well-defined architecture allocating roles, processes, and system requirements to enable secure and sovereign data sharing among multiple participants. It should be noted that alternative implementations of data space connectors have emerged (see, e.g., the IDS Data Space Connector Report https://internationaldataspaces.org/data-space-connector-report/ (accessed on 14 May 2026). In this work, the IDS implementation is adopted for continuity with previous studies and for demonstrative purposes.

As a result, the proposed architecture follows the International Data Spaces Reference Architecture Model, which structures trusted data exchange across five architectural layers and additional cross-cutting perspectives (e.g., security, certification, and governance) [8]. These layers are operationalized as follows:

- Business Layer: Defines the roles and responsibilities within the ecosystem. It distinguishes between Data Providers (in the current case farmers or sensor networks), Data Consumers (e.g., AGEA or agronomic consultants), and Intermediaries (e.g., agricultural assistance centers acting as data processors).

- Functional Layer: Specifies the technical requirements for establishing trust and managing data contracts. It ensures that data are not merely "sent," but "traded" under specific legal and technical agreements.
- Information Layer: Focuses on semantic interoperability. It utilizes the IDS Information Model, based on Linked Data principles (RDF/OWL), to ensure that a "land parcel" defined in a farmer's local system is identical in meaning when received by the SIAN database.
- Process Layer: Governs the interaction patterns. It manages the lifecycle of a data exchange, from the initial discovery of a dataset in a Metadata Broker to the final execution of a data transfer.
- System Layer: Defines the physical software components, primarily the IDS Connector, which acts as the sovereign gateway for every participant in the Italian agricultural data space.

The IDS reference architecture provides a set of ODRL-based usage policies that can be adapted to the specific needs of agriculture. These include policies for access control (e.g., restricting data access to certified stakeholders), purpose limitation (e.g., permitting use only for agronomic analysis or research), temporal constraints (e.g., limiting data usage to a predefined period), spatial constraints (e.g., restricting the use of georeferenced farm data to specific regions), data forwarding restrictions (e.g., prohibiting redistribution to third parties), and obligation policies requiring attribution, logging, or deletion after use. Such policy mechanisms are particularly relevant in agriculture, where farmers and agri-food stakeholders require fine-grained control over sensitive operational and production data.

5. Regulatory Framework

If the Common European Data Space Communication sets up the initial framework for the design and development of sectorial data space, such infrastructure should consider, and implement the requirements set by, the already existing legal framework addressing the data exchanges, in case of personal and non-personal data. In particular, the applicable European legislation is the General Data Protection Regulation addressing the protection of personal data, and the more recent Data Governance Act and Data Act, addressing the reuse of both personal and non-personal data. It is true that other legislative interventions, addressing cybersecurity and intellectual property, can affect design choices of the data space architecture; however, they will be outside the scope of the current contribution.

5.1. General Data Protection Regulation (GDPR)

The GDPR, formally Regulation (EU) 2016/679, constitutes the foundational legal framework governing the processing of personal data within the European Union. Regardless of the context of application, whether online or offline, the GDPR provides binding constraints whenever processing activities address information that qualifies as personal data (Art. 4 (1) GDPR). The regulation defines a set of key actors, namely the Data Subject, Data Controller, and Data Processor with specific tasks, obligations and rights [27,28]. In the IDS architecture, such actors can be translated into data space components. For instance, an organization operating an IDS Connector that processes personal data typically acts as a data controller, as it determines the purposes and means of processing. Conversely, a receiving participant may assume the role of a data processor if processing is strictly executed on behalf of the controller. Alternatively, an individual operating as IDS connector can transfer his/her personal data to a receiving participant who assumes the role of a data controller for the purposes of specific data processing.

The GDPR establishes a set of fundamental principles, including lawfulness, fairness and transparency, purpose limitation, data minimization, and accountability (Art. 6 GDPR). These principles require stringent transparency and policy enforcement mechanisms in distributed environments. Furthermore, the regulation grants data subjects, i.e., any individual whose personal data are collected, held, or processed, enforceable rights such as the right to access, data portability, and the right to erasure (Arts 12–23 GDPR). In the IDS framework, the effective exercise of these rights requires robust mechanisms for data provenance tracking and coordinated enforcement across multiple participants.

Additionally, Article 32 requires the implementation of technical and organizational measures, such as encryption and/or pseudonymization, to ensure a level of security appropriate to the risk of data processing. When these safeguards fail, Articles 33 and 34 mandate data breach notification procedures, requiring controllers to notify supervisory authorities within 72 h and, under specific conditions, inform affected data subjects. High-risk processing further mandates a Data Protection Impact Assessment (DPIA) under Article 35. Ultimately, the GDPR functions as a primary design driver for IDS, shaping the technical implementation of usage control, accountability, and traceability when dealing with personal data processing.

5.2. Data Governance Act (DGA)

The DGA, formally Regulation (EU) 2022/868, is a critical pillar of the European data strategy aimed at promoting trust in data sharing and facilitating data reuse across sectors and Member States. While the GDPR focuses on the data processing activity, the DGA addresses the organizational and institutional conditions necessary for secure and transparent multi-party data sharing beyond the relationship between data subject and data controller. Applying to both personal and non-personal data, the DGA complements existing regulations without replacing them.

A central contribution of the DGA is the establishment of a regulatory framework for data intermediation services (Articles 10 to 15). These services act as trusted, neutral third parties that enable data exchange between data holders and data users. The definitions of data holder and data users differ from the ones in the GDPR as the scope of application of the DGA extends also to non-personal data, upon which the legislation does not apply. In case of personal data, the role of data holder overlaps with the data controller, while the data user can become a new data controller in case personal data are processed for a different purpose. The regulation imposes strict transparency and organizational separation requirements to prevent conflicts of interest, explicitly prohibiting intermediaries from exploiting the shared data for their own commercial benefit. Within the context of IDS, these provisions directly support the roles of metadata brokers, catalog services, and coordination components, which are expected to operate transparently.

The regulation also mandates appropriate technical and organizational safeguards for data reuse, such as access controls and secure processing environments. In the IDS architecture, these safeguards can be technically translated into authenticated communication channels (e.g., mutual TLS) and federated identity services like the Dynamic Attribute Provisioning Service (DAPS). In the proposed simplification framework brought forward with the Digital Omnibus regulation proposal, the DGA will be repealed, and its provisions should become part of the EU Data Act.

5.3. Data Act and the Economic Dimension of Data Access

The Data Act, formalized as Regulation (EU) 2023/2854, regulates data access and use in multi-actor environments, focusing on the economic dimensions of data sharing. Its primary objectives include fostering a competitive data-driven economy, ensuring fair access, and reducing power imbalances between data holders and third-party recipients. Similar to DGA, the terminology used is not overlapping with the one of the GDPR, due to the wider scope of application of Data Act also to non-personal data. In case of personal data processing, the data holder overlaps with the role of data controller, while the user can be either a data subject or a third party acting on behalf of the data subject (see [29]). The regulation specifically targets data generated by connected products and related services, applying to both personal and non-personal data while complementing the GDPR.

Articles 3 and 4 of the Data Act establish the enforceable right of users to access data generated by their connected products without undue delay, free of charge, and in a structured, machine-readable format. Furthermore, Article 5 empowers users to mandate data holders to share these data with designated third-party recipients under fair, reasonable, and non-discriminatory conditions. To foster a balanced ecosystem, Article 13 introduces stringent safeguards against unfair contractual terms unilaterally imposed in business-to-business data sharing agreements, rendering excessively restrictive clauses unenforceable.

The regulation also imposes obligations to remove technical and organizational obstacles that hinder data portability, thereby facilitating seamless switching between service providers. For data space infrastructure models, Article 33 introduces essential interoperability requirements. Participants offering data must ensure datasets are accompanied by comprehensive machine-readable metadata detailing content, usage conditions, and data quality. Additionally, data structures and vocabularies must be consistent, access interfaces must be transparent, and smart contract mechanisms must be interoperable across participants. Consequently, the Data Act translates high-level economic principles into concrete technical constraints, strengthening the position of data users and mandating standardized exchange mechanisms within robust data spaces.

5.4. Agricultural Sector Specificities

From the point of view of data, agricultural data are uniquely "hybrid"; a single dataset such as machine telemetry during harvest, can simultaneously embed industrial data (yield metrics) and personal data (the farmer's location and professional behavior) [30]. This hybridity requires a dual-compliance strategy in data sharing activities that incorporates both the economic incentives of the Data Act with the privacy protection of the GDPR.

A cornerstone of this sectoral framework is the EU Code of Conduct on Agricultural Data Sharing by Contractual Agreement (COPA-COGECA, CEMA) in 2018. Although a "soft law" instrument, it introduced the seminal concept of the "Data Originator", granting the farmer a leading role in controlling data access, a principle that mirrors the IDS objective of data sovereignty. The integration of these institutional registries into an IDS-compliant data space addresses the "administrative burden" by enabling the principle of "once-only" data submission. Moreover, by utilizing IDS usage control, the architecture mitigates the specific agricultural risk of "vendor lock-in," where proprietary machine silos currently prevent farmers from porting their co-generated data to third-party advisors or competing manufacturers.

6. A Data Space for Agriculture: Analysis of the Italian Context

Prior work focuses on EU-level conceptual frameworks or high-level sectoral blueprints; this study integrates Italian regulatory constraints, real administrative burdens, and data heterogeneity into a single, coherent architectural model. We propose a classification matrix spanned by agricultural data categories and the layers of the IDS reference architecture. We then analyze potential benefits of a data space approach to interoperability as well as data value in Common Agricultural Policy-based data infrastructures.

6.1. Agricultural Data Taxonomy

The agricultural data taxonomy introduced in this work, comprising Farm Structure Data, Processing-Related Data, Administration Data, and Communication Data, can be systematically mapped onto the five-layer Reference Architecture Model (RAM) defined by the International Data Spaces Association. While the IDS RAM provides horizontal architectural abstraction, the proposed taxonomy represents a vertical, domain-specific interpretation tailored to agricultural supply chains and digital farming ecosystems. Recent research on agricultural data spaces emphasizes the importance of farm-centered data governance and the need to structure heterogeneous agricultural datasets in ways that preserve farmer data sovereignty and facilitate interoperable sharing across stakeholders, as discussed in [21]. Building on this broader perspective, the taxonomy proposed here focuses specifically on the operational classification of agricultural datasets and their architectural positioning within the IDS framework [6].

Farm Structure Data describe the relatively stable characteristics of an agricultural holding and its physical assets. It includes information such as land parcels, cadastral boundaries, farm identifiers, permanent facilities, machinery inventories, livestock registers, and crop types. These datasets define the structural configuration of the farm and constitute a fundamental reference layer for both agricultural management and administrative procedures. Unlike operational data generated by sensors or machinery, structural data are typically produced through institutional registries or declarative processes. For example, cadastral information and farm identifiers are maintained in public registries, while livestock inventories and crop declarations are periodically reported by farmers to authorities for regulatory compliance. Within the Information Layer of the IDS Reference Architecture, structural data are represented by shared semantic models that define entities such as assets and identifiers. Technical interoperability is managed at the System Layer through trusted connectors and metadata catalogs that enable controlled discovery. From a functional perspective, the Process Layer utilizes these data to support administrative workflows, such as subsidy applications and certification. Sovereignty is maintained in the Governance Layer via strictly defined usage policies, while the Business Layer realizes value by reducing redundant reporting and improving cross-actor coordination.

Processing-Related Data refers to information generated during agricultural production activities and operational workflows. These datasets capture the dynamic aspects of farming processes and provide insight into crop management, livestock care, and resource utilization. Typical examples include environmental observations such as soil moisture or weather conditions, crop yields, fertilizer and pesticide applications, animal health and feeding cycles, and resource consumption such as water, seeds, or energy. In contrast to structural data, process-related information is often automatically generated by agricultural machinery, IoT sensors, and digital farm management platforms. These data streams are frequently stored within proprietary systems operated by machinery manufacturers or digital service providers, which may limit interoperability and farmer control over data reuse. In the IDS model, this information is modeled in the Information Layer using standardized representations for sensor observations. The System Layer facilitates secure, integrated access to these data streams (which are often proprietary) through certified connectors. Agronomic monitoring and sustainability assessments are orchestrated within the Process Layer, while the Governance Layer regulates confidentiality and permits reuse to protect commercially sensitive operational details. At the Business Layer, the sharing of process data enables advanced predictive analytics and the optimization of resource consumption.

Administration Data comprises information exchanged between farms and institutional actors in the context of regulatory compliance, certification, and commercial transactions. Typical examples include subsidy applications and declarations, invoices and orders, insurance documentation, product shipment records, certification documents, and inspection reports. These datasets are generated through formal administrative procedures involving public authorities, certification bodies, financial institutions, and agricultural intermediaries. In many agricultural systems, farmers must repeatedly submit similar information to different institutions, often through heterogeneous digital platforms and data formats. Such fragmentation increases administrative complexity and may create inconsistencies between datasets maintained by different actors. Within an agricultural data space, these artifacts are standardized in the Information Layer to represent certificates and transaction records. The System Layer employs certified connectors and metadata catalogs to ensure the secure exchange of these sensitive documents. Institutional workflows, including regulatory inspections and subsidy management, are coordinated in the Process Layer. To ensure data protection, the Governance Layer establishes rigorous policies for retention and access. The primary Business Layer outcome is a significant reduction in administrative burden for farmers and enhanced transparency for financial and public authorities.

Communication Data captures interactions and information exchanges among stakeholders in the agricultural ecosystem, including farmers, advisors, cooperatives, digital platforms, and consumers. Examples include advisory messages, feedback from consumers or supply-chain partners, quality evaluations, and marketing-related information associated with agricultural products or farming practices. These datasets are typically generated through advisory platforms, messaging services, farm management systems, and online marketplaces. These data are integrated into the IDS Information Layer through structured metadata describing feedback records and recommendations. The System Layer provides the necessary secure channels for the dissemination of these communication artifacts. Collaborative workflows, such as consumer engagement mechanisms and quality evaluations, are supported by the Process Layer. Because these data can contain personal or sensitive information, the Governance Layer defines critical policies for anonymization and visibility. Finally, the Business Layer leverages these exchanges to foster producer-consumer trust and facilitate market differentiation through improved traceability services. A classification of agricultural data categories, data sources, and application scenarios in the Italian agricultural ecosystem is listed in Table 2. The mapping from agricultural data categories to the respective layers in the IDS Reference Architecture is illustrated in Table 3.

Table 2. Classification of agricultural data categories, data sources, and application scenarios in the Italian agricultural ecosystem. Blue background indicates the primary data category grouping.

Data Category	*Typical Sources*	*Representative Data*	*Main Stakeholders*	*Application Scenarios*
Farm Structure Data	Cadastral systems, farm registries, livestock databases	Land parcels, farm identifiers, crop types, livestock records	Farmers, public authorities	CAP applications, certification, compliance
Process-Related Data	Agricultural machinery, IoT sensors, FMIS platforms	Yield data, soil moisture, GPS tracks, machine telemetry	Farmers, agronomists, machinery providers	Precision agriculture, monitoring, operational optimization
Administrative Data	AGEA, SIAN, CAAs, public administrations	CAP declarations, subsidy requests, inspection reports	Farmers, paying agencies, regional authorities	Subsidy management, inspections, regulatory reporting
Communication Data	Advisory platforms, farm management systems, marketplaces	Recommendations, quality evaluations, consumer feedback	Farmers, cooperatives, consumers	Traceability, advisory services, market communication

Table 3. Mapping of agricultural data categories to the respective layers of the IDS reference architecture. Blue background indicates the primary data category grouping.

Layer	*Farm Structural Data*	*Process-Related Data*	*Administrative Data*	*Communication Data*
Governance Layer	Define usage policies, access rights	Regulate data access, confidentiality, permitted use	Establish strict policies for access, retention, and compliance	Policies for visibility, traceability, and anonymization of records
Business Layer	Reduce redundant reporting, improve efficiency	Improved farm management, predictive analytics, optimized resource use	Interoperable exchange reduces reporting burdens and improves efficiency	Support advisory services, producer–consumer trust, differentiation
Process Layer	Support workflows like subsidy applications and certification procedures	Coordinate agronomic certification reporting and sustainability assessment	Orchestrate institutional workflows, subsidy management, and inspections	Support advisory workflows, quality evaluation, consumer engagement
Information Layer	Shared semantic models describing entities like parcels, assets, and identifiers	Standardized data models for sensor observations, operational records	Standardized representations of declarations and transaction records	Structured metadata describing messages, recommendations, feedback records
System Layer	Trusted connectors, catalogs, discovery, controlled access	Secure access through trusted connectors and integration services	Secure discovery, exchange, certified connectors, metadata catalogs	Secure channels for disseminating artifacts

6.2. Administrative Data Systems and Information Flows in Italian Agriculture

The Italian agricultural sector is characterized by a complex network of administrative and operational data exchanges involving farmers, intermediaries, public authorities, and private technology providers. Data flows do not occur within a single integrated infrastructure; instead, they are distributed across multiple institutional and proprietary systems operated by national authorities, regional administrations, cooperatives, and machinery manufacturers. This fragmented ecosystem results in duplicated data submissions, heterogeneous formats, and limited interoperability across information systems. Similar challenges have been reported in studies on digital transformation and data sharing in Agriculture 4.0, where the proliferation of heterogeneous data sources creates significant barriers to interoperability and coordinated decision support [31].

To contextualize this complexity, Figure 1 provides a conceptual overview of the main administrative information flows associated with Italian farmers. In this representation, the farm acts as the central data producer from which several parallel declarative processes originate. Each of these flows targets a specific public authority responsible for regulatory or administrative functions. At the legal and business level, farmers must register their activity with the Chamber of Commerce (*Camera di Commercio*), which maintains the national Business Register and records agricultural enterprises as regulated by the Italian Civil Code, Article 2188 ([32] in Italian). Registration in the Business Register for all agricultural enterpreneurs is mandatory. The mandatory nature is further reinforced by DPR 588/1999, Art 2, which simplifies the legal framework governing the Business Register by establishing a special section dedicated to the registration of agricultural entrepreneurs. Public health obligations generate additional information flows toward local health authorities (*Azienda Sanitaria Locale, ASL*), where food-producing farmers must submit documentation related to Hazard Analysis and Critical Control Points (HACCP). The obligation to establish and maintain HACCP documentation derives from Article 5 of the Regulation No 852/2004 ([33], in Italian) on the hygiene of foodstuffs of the European Commission. In Italy, the competent authorities responsible for official food safety controls are designated in Decree. 193/2007, Article 2 ([34], in Italian). These authorities may also interact with sector-specific registries such as the Banca Dati Nazionale (BDN) for livestock identification and traceability. Fiscal and social security obligations introduce further administrative exchanges, including tax declarations submitted to the Italian Revenue

Agency (*Agenzia delle Entrate*) in accordance with Article 62 of Decree.300/1999, ([35] in Italian) and employment-related information communicated to the Italian Social Security Institute (*Istituto Nazionale della Previdenza Sociale*—INPS) in accordance with Law 233/1990 ([36] in Italian).

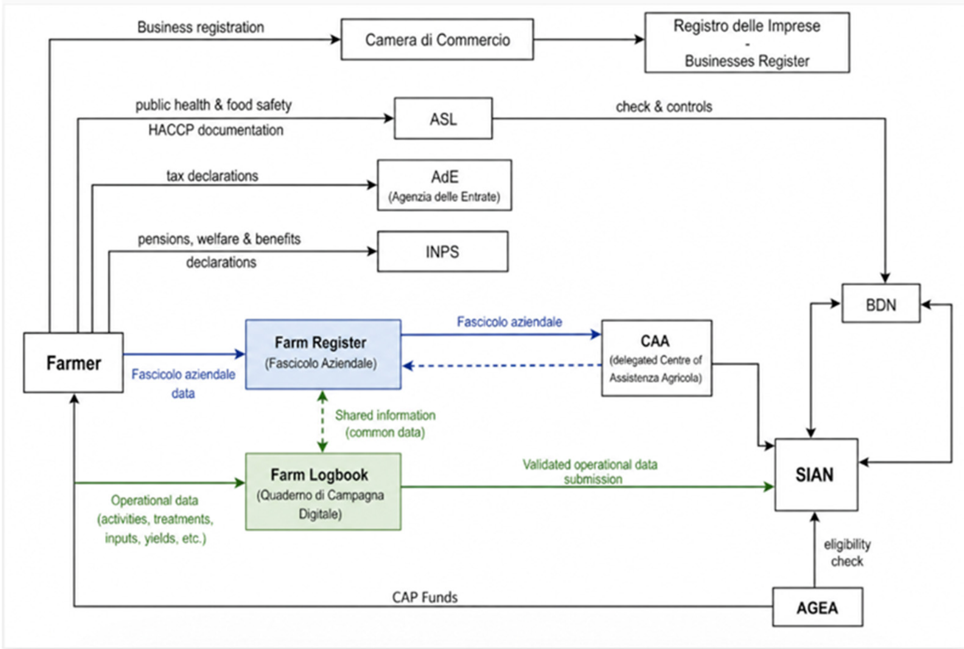

Figure 1. High-level visualization of core data flows for CAP subsidies in Italy. (not exhaustive).

In addition to these institutional obligations, any Italian farmer must create of a so-called Farm Register (*Fascicolo aziendale*), which serves as the "single source of truth" for subsidies and compliance with legislation. The Farm Register, established by Presidential Decree 503/1999, includes all the information that the farmer has to provide to the public administration in an organized and standardized manner, and it provides the supporting element to be evaluated for the allocation of national and regional measure pursuant the Common Agricultural Policy (CAP) [37]. It must be highlighted that Farm Register can also be managed by a different institutional body, namely the Agricultural Assistance Centre (*Centro di Assistenza Agricola*—CAA), which is entrusted of the creation and management of the register through a specific contractual mandate. Their involvement is particularly significant in procedures related to the European Union's Common Agricultural Policy (CAP), where validated declarations are transmitted through centralized information infrastructures used for subsidy administration according to Regulation (EU) 2025/2203: Commission Implementing Regulation of 31 October 2025 Amending Implementing Regulation (EU) 2023/564 as Regards the Transfer into Electronic Format of the Records of Plant Protection Products Kept by Professional Users. Available online: http://data.europa.eu/eli/reg_impl/2025/2203/oj (accessed on 14 May 2026).

In parallel, recent regulatory developments at the European level have introduced the progressive obligation to maintain agricultural activity records in digital and machine-readable formats, commonly referred to as the digital farm logbook (*quaderno di campagna digitale*). This requirement is expected to further standardize the collection of agronomic and operational data, strengthening their integration within administrative information systems and enabling their reuse across multiple regulatory and management processes.

A central administrative data flow in this ecosystem is associated with the management of CAP subsidies. In Italy, this process is coordinated by the Agency for Agricultural Payments (*Agenzia per le Erogazioni in Agricoltura—AGEA*), which oversees the distribution of CAP funds and ensures compliance with European agricultural regulations ([38], in Italian). To support this process, AGEA operates the National Agricultural Information System (*Sistema Informativo Agricolo Nazionale*—SIAN), a centralized information infrastructure integrating datasets originating from multiple actors within the agricultural sector. Similar integrated agricultural information systems exist across Europe to support CAP management and land parcel monitoring, reflecting the growing importance of interoperable agricultural data infrastructures in policy implementation [39].

The SIAN platform integrates several categories of administrative and operational datasets required for the management of CAP funding. These include administrative identification data such as farmer identity, fiscal codes, and land ownership documentation; geospatial and land-use information describing agricultural parcels and crop declarations through the Land-parcel identification system (*Sistema di Identificazione delle Parcelle Agricole*—SIPA); livestock identification and veterinary records obtained from the BDN registry; and CAP application datasets containing subsidy requests, eligibility assessments, inspection reports, and payment decisions. Additional datasets include energy consumption records associated with agricultural machinery fuel quotas managed through some kind of agricultural fuel register, dubbed *Utenti Motori Agricoli* (UMA), as well as environmental and climate-related data required for sustainability schemes and cross-compliance obligations.

Although these datasets are centralized within SIAN, their production is distributed across several actors including farmers, CAAs, regional administrations, certification bodies, and inspection authorities. A central procedural element in this workflow is the annual CAP subsidy declaration known as the *Domanda Unica*. This declaration aggregates administrative, agronomic, and compliance-related information describing farm structure, agricultural parcels, and environmental practices. In practice, the declaration is typically compiled by a CAA with the support of the farmer and then submitted through the SIAN system for verification by AGEA prior to the authorization of subsidy payments.

This administrative workflow highlights a structural inefficiency within the agricultural data ecosystem. Because multiple institutions require overlapping information, farmers frequently need to submit identical or partially redundant datasets across different administrative procedures and digital platforms. Similar challenges have been documented in recent research on agricultural data management, where institutional fragmentation and lack of standardization significantly limit interoperability between agricultural information systems [19,40].

Alongside these administrative processes, the Italian agricultural sector is increasingly characterized by a second major category of data flow: machine-generated data originating from precision agriculture technologies. Modern agricultural machinery such as tractors, harvesters, fertilizer spreaders, irrigation systems, and environmental sensors continuously generates operational data during field activities. These datasets typically include technical data describing machine performance (e.g., engine metrics, fuel consumption, and GPS position), agronomic data related to field operations (e.g., fertilizer application rates or yield measurements), and environmental data describing soil and climatic conditions. In scenarios without internet connectivity, data generated by agricultural machinery are locally buffered within onboard or edge storage systems. Transmission to external platforms occurs asynchronously once connectivity is restored, supporting data integrity through caching and breakpoint resumption mechanisms.

The lifecycle of machine-generated data typically follows a multi-stage pipeline. Sensors embedded within agricultural equipment first collect data during field operations. These observations may be temporarily aggregated within the machine's onboard systems before being transmitted through cellular connectivity or local wireless networks. Subsequently, the data are uploaded to proprietary cloud platforms operated by machinery manufacturers, where they are processed and visualized through dashboards designed to support farm management and decision-making. However, the management of these datasets often occurs within closed proprietary ecosystems characterized by non-standard formats and restricted application programming interfaces. This situation may limit farmers' ability to reuse or share data generated by their own machinery and may lead to vendor lock-in effects.

From the perspective of the IDS-RAM, these two major categories of agricultural data flows, namely administrative declarations and machine-generated operational data, can be interpreted across multiple architectural layers. At the business layer, the ecosystem includes farmers, public authorities such as AGEA, intermediaries such as CAAs, and private technology providers including machinery manufacturers and digital platform operators. The information layer encompasses heterogeneous datasets ranging from administrative declarations and parcel records to sensor observations and agronomic performance metrics. At the process layer, interactions include declarative procedures such as CAP subsidy applications as well as automated machine-to-cloud data transmissions. Finally, the system layer is represented by the digital infrastructures supporting these exchanges, including institutional platforms such as SIAN and proprietary cloud services for precision farming.

Relating this existing information flow onto the IDS layered architecture highlights the potential benefits of a data space approach for agricultural data management. Data spaces have been proposed as a mechanism to enable decentralized yet trustworthy data sharing across heterogeneous stakeholders while preserving data sovereignty and usage control. By enabling standardized metadata models, policy-controlled access mechanisms, and secure connector-based exchanges, IDS-based data spaces can facilitate interoperability between institutional agricultural systems and private digital farming platforms. Such architectures are increasingly considered a key enabler for the development of agricultural data ecosystems that support collaboration, transparency, and innovation across the agri-food value chain [1,41].

7. Use Cases of Agricultural Data Sharing

The digital transformation of agriculture has led to the generation of large volumes of heterogeneous data originating from farms, agricultural machinery, advisory services, and public administrations. These datasets are increasingly important for farm management, regulatory compliance, and coordination along agri-food supply chains. However, agricultural data are often fragmented across multiple information systems and organizational silos, preventing interoperability between agricultural information systems and limiting the effective reuse of valuable datasets. It also increases the administrative burden for farmers and restricts the development of innovative digital services. Recent initiatives in agricultural data governance therefore emphasize secure and sovereign data sharing, enabling stakeholders to exchange data while maintaining control over access and usage conditions.

To illustrate typical situations in which agricultural data must be exchanged, we present three representative use cases derived from an analysis of data flows in the Italian agricultural sector. The first focuses on administrative data exchange related to subsidy declarations under the CAP. The second addresses the portability and reuse of machine-generated data from agricultural machinery and IoT systems. The third examines traceability and sustainability-related data exchanged along agri-food supply chains. The three use cases discuss the importance of data sharing in increasingly complex scenarios: the first discusses the request of CAP subsidies, as very commonly put forward by farms of all sizes; the second examines farm-level data to improve operations, which require FMIS and thus is usually prerogative of medium and large farms; and the third addresses traceability of products and sustainability information, which mostly depend on the availability of FMIS at the farm level, and can be seen as an effort to improve transparency and also gain a competitive advantage on the market.

7.1. Administrative Data Sharing for CAP Subsidy Declarations

Administrative procedures for agricultural subsidies are highly data-intensive under the CAP [42]. Farmers applying for support must provide detailed information on land parcels, crop types, and management practices. This information is often shared with multiple actors involved in the subsidy process. In Italy, many farmers rely on CAA, which act as intermediaries between farmers and the national paying agency, assisting with data verification and application preparation. However, farm information is frequently distributed across different administrative databases, creating inconsistencies and duplication. Resolving discrepancies between farm records and official registries can increase administrative complexity and delay the submission and evaluation of subsidy applications. A coordinated data-sharing environment can simplify this process by enabling structured exchange of agricultural and administrative data between the main stakeholders involved in subsidy management, compliant with the legislative framework both at the national and European levels.

The scenario involves three primary actors: the farmer, the CAA, and the Italian paying agency AGEA. These actors can be qualified according to the roles defined by the GDPR, the Data Act and the DGA: the farmer acts as the primary data holder (and eventually data subject), maintaining farm-related information required for subsidy applications. The CAA functions as a data intermediary, through the collection of relevant data it supports the farmer in preparing and validating the application, then it transfers the application to the data user. AGEA is in this case the data user, as it is the public authority responsible for evaluating eligibility and administering CAP payments. According to the roles allocated, each actor participates in the data space through an IDS connector, enabling secure and policy-controlled data exchange.

Two datasets are involved in the process. The first dataset contains raw farm-level information provided by the farmer, including identification details, land parcel declarations, farm profile attributes, and environmental practices. This dataset reflects the original information maintained by the farmer and is not yet structured for the subsidy application. The second dataset is derived from the first by the CAA and represents a semantically complete *Domanda Unica* subsidy application. It includes farmer identification, farm profile declarations, payment information, parcel-level data, environmental measures, support requests, and legal declarations required for eligibility verification. The collection and re-organization of the data provided by the data holder to the data intermediary, given that it involves also personal data, can be qualified as data processing activity, and it should comply with the GDPR requirements mentioned above in Section 5.1, in particular, data minimization, purpose limitation and adoption of security measures.

The interaction follows a multi-stage data sharing workflow. First, the farmer publishes the raw dataset through an IDS connector together with metadata and usage policies. Here, the data holder can define the conditions for data processing, the type of data that can be processed and the purpose accepted. The CAA discovers the dataset through the data space catalog, negotiates a contract with the farmer, eventually confirming or negotiating the usage policies, and retrieves the data once the agreement is established (and consent is provided). The CAA then validates and transforms the data into a structured subsidy application dataset. Finally, the CAA publishes the derived dataset with contractual restrictions limiting access to AGEA, which retrieves the information to perform subsidy evaluation and verification.

In this way, we reduce redundant submissions while ensuring traceability, usage control, and secure administrative data sharing across the agricultural ecosystem.

7.2. Portability of Machine-Generated Agricultural Data

Machine-generated data have become a key resource in modern agriculture due to the widespread adoption of precision farming technologies and connected agricultural machinery. However, such data are typically collected and stored within proprietary platforms managed by machinery manufacturers, creating interoperability barriers and limiting farmers' ability to reuse their own operational data across different service ecosystems. The use case presented in this work illustrates how an agricultural data space based on the IDS architecture can enable controlled portability of machine-generated agricultural data when a farmer decides to switch machinery providers. Given that, in this case, data are not qualified as personal data, the legal framework applicable is the one defined by the Data Act and the Data Governance Act.

The scenario involves three actors operating as IDS participants through dedicated connectors. The farmer is the primary data rights holder, as agricultural activities performed on the farm generate the data through precision farming equipment. Through the lenses of the Data Act, it is qualified as user. Manufacturer A represents the original machinery provider and acts as the data holder, maintaining the machine-generated dataset within its proprietary platform. Manufacturer B represents the new machinery provider selected by the farmer and acts as the future service provider as well as the designated data consumer. Through the lenses of the Data Act, the latter is qualified as data recipient.

The dataset considered in the use case consists of accumulated machine-generated operational data associated with a specific farm and reference year. According to the agricultural data taxonomy introduced above, this dataset belongs to the category of processing-related data. It includes records of field operations executed by connected machinery and is organized around the farm's land parcels. Each parcel contains one or more operations classified by operation type and season, together with temporal information, execution status, and aggregated indicators such as field coverage, working speed, overlap rate, and execution completeness. According to the data portability principle defined by Article 5 of the Data Act, the user (farmer) can mandate data holder (Manufacturer A) to share machine readable data with a designated data recipient (Manufacturer B) under fair, reasonable, and non-discriminatory conditions.

Within the data space interaction workflow, the legal conditions can be translated into usage policies: Manufacturer A first publishes the dataset through its IDS connector, making the metadata discoverable without granting immediate access to other participants of the dataspace. The farmer then initiates a contract negotiation defining the portability conditions and explicitly authorizes Manufacturer B as the permitted data recipient. Once the contract agreement is established, Manufacturer B retrieves the dataset directly from Manufacturer A through authenticated data transfer.

This workflow demonstrates how IDS mechanisms enable farmer-centric control over machine-generated data while preserving interoperability, traceability, and enforceable usage policies across heterogeneous agricultural technology ecosystems.

7.3. Data Sharing for Traceability and Sustainable Agri-Food Supply Chains

Traceability is a fundamental requirement in modern agri-food systems to ensure food safety, quality assurance, sustainability, and transparency across complex supply chains. However, agri-food supply chains involve multiple independent stakeholders, such as farmers, logistics providers, processors, and retailers, each operating heterogeneous information systems. These fragmented digital infrastructures hinder interoperability and limit the effective exchange of traceability information between actors. The use case described in this work illustrates how a data space architecture can enable secure and interoperable data sharing to support traceability and sustainability monitoring across the agri-food supply chain.

The scenario focuses on the transportation and post-harvest phases of agricultural products, where monitoring environmental conditions and logistics events is critical for ensuring product quality and regulatory compliance. Several actors participate in the data-sharing ecosystem through IDS connectors. The primary data providers include producers and logistics operators that generate operational data during production and transport activities. Logistics operators deploy IoT sensors to continuously collect environmental parameters such as temperature, humidity, and location during storage and transportation. Downstream actors, including processors, retailers, and certification bodies, act as data consumers that require access to traceability information to verify product provenance and sustainability compliance. Similarly to the previous case, the Data Act applies to the data sharing agreements along the supply chain. In this case, the usage policies embedded in the initial transfer from the user (farmer) to the logistic provider (data holder) can provide the conditions for the subsequent data sharing agreements with processors, retailers, etc. (data recipients).

Within the agricultural data space, operational data collected along the supply chain are published through IDS connectors together with metadata and usage policies. This mechanism allows stakeholders to maintain sovereignty over their proprietary datasets while enabling controlled access to authorized participants. Data consumers discover the available datasets through the data space catalog and negotiate usage contracts defining the permitted access conditions. Once agreements are established, the relevant traceability data can be retrieved and integrated into supply chain monitoring or certification systems.

The resulting framework supports interoperable traceability across organizational boundaries, enabling stakeholders to verify product provenance, monitor transport conditions, and audit sustainability practices.

Table 4 summarizes scenarios and actors, data involved, workflow, IDS mapping, and evaluation against criteria. Figure 2 illustrates the agricultural data sharing process within the three use cases.

Table 4. Summary of scenario, data involved, workflow and IDS Mapping for each use case. Blue background indicates the primary data category grouping.

Use Case	*Scenario & Actors*	*Data Involved*	*Workflow*	*IDS Mapping*	*Evaluation Approach*
CAP Administrative Data Sharing	Farmers, CAAs, AGEA in CAP subsidy applications	Farm identifiers, land parcels, crop declarations, compliance data	Farmer submits datasets; CAA negotiates contracts, validates applications; AGEA retrieves data and evaluates subsidy eligibility	Business: actors; Info: datasets; Process: submission; System: SIAN/IDS; Governance: policies	Process efficiency (time reduction), data consistency, traceability of submissions
Machine-Generated Data Portability	Farmer, Manufacturer A (source), Manufacturer B (recipient)	Yield data, GPS tracks, machine telemetry	Farmer mandates Manufacturer B to transfer machine data from Manufacturer A via secure IDS Connectors.	Business: actors; Info: sensor data; Process: portability; System: connectors; Governance: usage policies	Transfer success rate, data integrity, transfer time, interoperability
Traceability in Agri-Food Supply Chains	Producers, logistics providers, retailers	Environmental data, transport logs, product metadata	IoT-sensors collect logistics data; stakeholders share traceability information for monitoring, provenance verification, and certification	Business: stakeholders; Info: traceability data; Process: sharing; System: secure connectors; Governance: access policies	Data availability, latency, auditability, compliance reliability

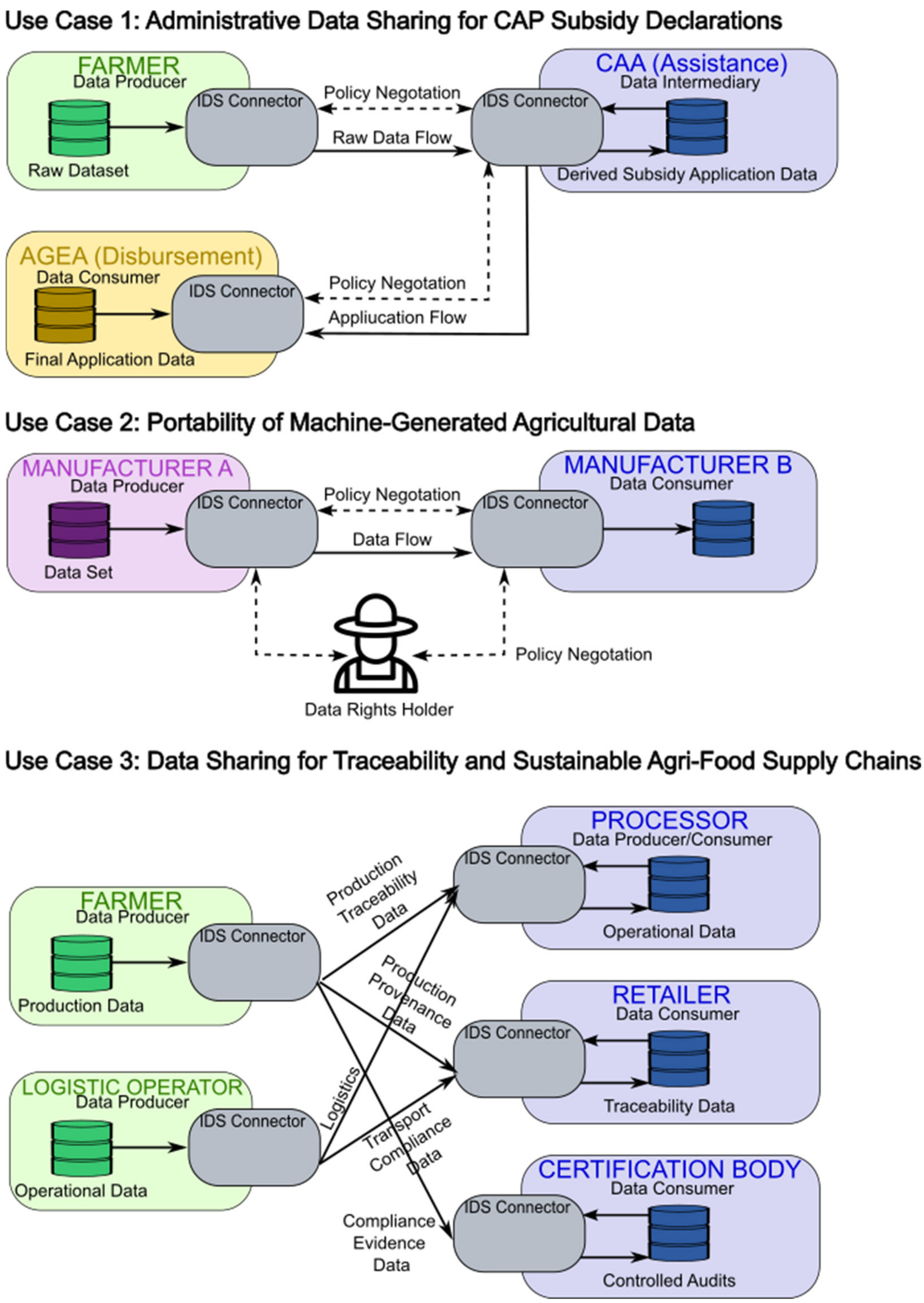

Figure 2. The agricultural data sharing process is illustrated by three use cases. Solid arcs represent data flows; dashed arcs indicate control flows. Control flows for Use Case 3 are omitted in the already overcrowded figure.

8. Discussion and Conclusions

The IDS reference architecture provides a set of ODRL-based usage policies that can be adapted to the specific needs of agriculture, where data streams from sensors, drones, satellite imagery and farm-management systems are increasingly shared across supply chain partners, research bodies and public authorities.

IDS-derived ODRL policies offer a machine-readable way of expressing permissions (e.g., “use for yield optimization”), obligations (e.g., “retain data for no longer than

12 months") and prohibitions (e.g., "no re-identification of individual farms"). Because the policies are anchored in a trusted connector model, they can be automatically negotiated and enforced at the point of data exchange. Moreover, the IDS ecosystem already includes tooling for policy verification and audit-logging, which facilitates traceability of data use throughout the agricultural value chain.

However, the ODRL vocabulary, while expressive, can be too coarse in some specific cases, such as conditional use based on climate-risk tiers or seasonal licensing windows. Translating specific needs, at different geographical and temporal scales, into IDS-compatible policy fragments may therefore require extensive work. Smaller farms and cooperatives may also lack the resources to integrate IDS connectors and maintain custom policy repositories, potentially exacerbating digital divide.

Under this premise, in this work, we discuss the mapping between the EU legal frameworks and the IDS-compliant architecture, considering specifically the case of agriculture in Italy. Secondly, we have discussed 3 case studies of increasing complexity that involve different agriculture stakeholders. From a technical standpoint, we observe that the integration of connectors into existing farm management platforms can be considered doable. A challenge could be in the development of sector-specific policy templates that are widely accepted. For data-intensive activities such as precision farming, supply-chain traceability, and collaborative research, IDS-based ODRL policies may provide a scalable governance mechanism. They enable data owners to retain control over exploitation of their data, while allowing authorized partners to access them to derive insights. In contexts involving highly sensitive personal data (e.g., farmer records), additional safeguards are surely needed.

Overall, leveraging IDS-provided ODRL policies in agricultural pilots appears technically viable; however, the extent of their concrete usability in real-world deployments remains to be seen. A key role might be played by intermediate actors. Centers of Agricultural Assistance (CAA), Cooperatives, Farm advisors, Farmers' associations, Product Consortia can foster the pooling of data and could benefit from the use of data for management, planning and providing services. Public actors, such as payment agencies, health authorities and tax agencies could contribute with open data and improving interoperability. Enhanced interaction between these bodies is the necessary condition for the activation of an agricultural data space.

This study presents an IDS-based framework for agricultural data sharing; however, several limitations must be acknowledged. First, the validation is primarily conceptual through use cases rather than large-scale empirical deployment in operational farming environments. Second, the Italian case study, while representative, may not fully capture the heterogeneity of agricultural systems across other European regions. Third, the proposed integration of regulatory requirements into ODRL policies is demonstrated at a logical level but not evaluated through full production-grade implementation. Finally, performance, scalability, and cybersecurity implications of IDS-based agricultural data spaces remain outside the scope of this work and require further investigation.

Future research should focus on the implementation of the considered use cases in real operational environments. In particular, pilot implementations across diverse agricultural regions would help assess scalability, interoperability, and performance under heterogeneous conditions. Further work is required to operationalize machine-enforceable regulatory compliance, extending ODRL-based policies into dynamic, context-aware governance mechanisms. Additionally, integration with emerging technologies such as edge computing, AI-driven decision support, and blockchain-based traceability systems could enhance data sovereignty and transparency. Finally, socio-economic impacts, including farmer adoption, cost–benefit analysis, and policy acceptance, should be systematically evaluated.

Author Contributions: Conceptualization, F.C. (Francesco Camaccioli), A.K., M.B., G.B., F.C. (Federica Casarosa) and S.C.; methodology, F.C. (Francesco Camaccioli), M.B., G.B., F.C. (Federica Casarosa) and S.C.; validation, F.C. (Francesco Camaccioli), M.B., G.B., F.C. (Federica Casarosa) and S.C.; investigation, F.C. (Francesco Camaccioli), A.K., M.B., G.B., F.C. (Federica Casarosa) and S.C.; writing—original draft preparation, F.C. (Francesco Camaccioli), A.K., M.B., G.B., F.C. (Federica Casarosa) and S.C.; writing—review and editing, A.K., M.B., G.B., F.C. (Federica Casarosa) and S.C.; visualization, F.C. (Francesco Camaccioli) and A.K.; supervision, M.B., G.B., F.C. (Federica Casarosa) and S.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

Disclaimer: The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

Abbreviations

The following abbreviations are used in this manuscript:

AdE	Agenzia delle Entrate (Italian Revenue Agency)
AGEA	Agenzia per l'erogazione in agricoltura (Agency for disbursements in agriculture)
AI	Artificial Intelligence
AKIS	Agricultural Knowledge and Innovation Systems
ASL	Azienda Sanitaria Locale (Local Health Authority)
BDN	Banca Dati Nazionale (National Livestock Database)
CAA	Centro di Assistenza Agricola (Agricultural Assistance Centre)
CAP	Common Agricultural Policy
CEMA	European Agricultural Machinery Association
CEDS	Common European Data Spaces
COPA-COGECA	Committee of Professional Agricultural Organisations-General Confederation of Agricultural Cooperatives in the EU
DAPS	Dynamic Attribute Provisioning Service
DGA	Data Governance Act (Regulation (EU) 2022/868)
DSSC	Data Spaces Support Centre
EU	European Union
FNSSA	Food and Nutrition Security and Sustainable Agriculture
FMIS	Farm Management Information Systems
GDPR	General Data Protection Regulation (Regulation (EU) 2016/679)
HACCP	Hazard Analysis and Critical Control Points
IDS	International Data Spaces
INPS	Istituto Nazionale della Previdenza Sociale (National Institute for Social Security)
IoT	Internet of Things
MQTT	Message Queuing Telemetry Transport
ODRL	Open Digital Rights Language
RAM	Reference Architecture Model
RDF/OWL	Resource Description Framework/Web Ontology Language
SIAN	Sistema Informativo Agricolo Nazionale (National Agricultural Information System)
SIPA	Sistema di Identificazione delle Parcelle Agricole (Agricultural Parcels Identification System)
UMA	Utenti Motori Agricoli (Agricultural Machinery Users Registry)

References

1. Gil, R.M.; Ryan, M.; García, R. Sovereignty by Design and Human Values in Agriculture Data Spaces. *Agric. Hum. Values* **2025**, *42*, 1413–1438. [CrossRef]
2. Brunori, G.; Bacco, M.; Puerta-Piñero, C.; Borzacchiello, M.T.; Stormer, E. Agri-Food Data Spaces: Highlighting the Need for a Farm-Centered Strategy. *Data Brief* **2025**, *59*, 111388. [CrossRef] [PubMed]
3. Kalmar, R.; Rauch, B.; Dörr, J.; Liggesmeyer, P. Agricultural Data Space. In *Designing Data Spaces*; Springer International Publishing: Cham, Switzerland, 2022; pp. 279–290.
4. Kosior, K. Towards a Common Agricultural Data Space in the European Union: A Sustainable Development Perspective. *Wieś I Rol.* **2021**, *2*, 65–89. [CrossRef]
5. Datta, S.K.; Bokan, T.; Resman, L. A Reference Architecture for Agricultural Data Spaces: Case Study from DIVINE Project. In *Proceedings of the 2025 International Wireless Communications and Mobile Computing (IWCMC)*; IEEE: New York, NY, USA, 2025; pp. 8–13.
6. Santos, F.; Schillaci, C.; Martin Jimenez, J.; De Medici, D.; Scarpa, S.; Bacco, M.; Friis-Christensen, A.; Kanakaki, S.; El-Aydam, M.; Tillie, P.; et al. Interoperability of Integrated Administration and Control System (IACS) and LUCAS Soil Data at EU Scale. *Farming Syst.* **2026**, 100207. [CrossRef]
7. European Soil Data Centre (ESDAC). *IACS Data Sharing Project—Final Report*; ESDAC: Ispra, Italy, 2023.
8. Boris, O.; Sebastian, S.; Andreas, T.; Sebastian, B. *Reference Architecture Model (RAM)*, version 4.2.0; International Data Spaces (IDS): Dortmund, Germany, 2023.
9. Wolfert, S.; Verdouw, C.; Piot-Lepetit, I. How Data and the Digital Technologies Are Shaping the Data Economy for Agrifood Systems. In *Digital Technologies for Sustainable Agriculture and Food Systems*; Elsevier: Amsterdam, The Netherlands, 2026; pp. 43–68.
10. Corcho, O.; Elena, S. *Data.Europa.Eu and the European Common Data Spaces*; European Union: Luxembourg, 2022.
11. van Eeckhout, J.; Dimic, M.; Angulo, C. Agrixel. AI-Based Service Standard for Agricultural Data in Agri-Food Use Cases. In *Artificial Intelligence Research and Development*; IOS Press: Amsterdam, The Netherlands, 2025; pp. 163–172.
12. Chrysakis, I.; Turkyamali, A.; Railis, K.; Oikonomidis, Y.; Zahariadis, T. Integrating Agricultural Semantic Models with Data Spaces for Enhanced Interoperability. In *Proceedings of the 2025 6th International Conference in Electronic Engineering & Information Technology (EEITE)*; IEEE: New York, NY, USA, 2025; pp. 1–6.
13. Ahoa, E.; Kassahun, A.; Verdouw, C.; Tekinerdogan, B. Challenges and Solution Directions for the Integration of Smart Information Systems in the Agri-Food Sector. *Sensors* **2025**, *25*, 2362. [CrossRef] [PubMed]
14. Martinez-Ruedas, C.; Pérez-Galvín, A.; Linares-Burgos, R. A Proof of Concept for an Agrifood Data Space Based on Open Data and Interoperability. *Appl. Sci.* **2026**, *16*, 1831. [CrossRef]
15. Kalatzis, N.; Paraskevopoulos, M.; Routis, G.; Roussaki, I. Smart Farming Data and IoT in Support of Agricultural Policy Monitoring. In *Proceedings of the 2024 IEEE International Conference on Omni-layer Intelligent Systems (COINS)*; IEEE: New York, NY, USA, 2024; pp. 1–8.
16. Bacco, M.; Kocian, A.; Crivello, A.; Gori, M.; Dimitri, G.M.; Barsocchi, P.; Brunori, G.; Chessa, S. Agricultural Data Space: The METRIQA Platform and a Case Study in the CODECS Project. In *Proceedings of the 2024 19th Conference on Computer Science and Intelligence Systems*; IEEE: New York, NY, USA, 2024; pp. 543–548.
17. Serna, R.S.; García, C.L.; González-Tablas, A.I. Data Spaces and Self-Sovereign Identity: Ecosystem Landscape and a Systematic Literature Review on Gaia-X-Aligned Data Spaces. *Data Brief* **2026**, 112668. [CrossRef]
18. Singh, A.K.; Sánchez, M.O.; Caparros, M.G.; de los Mozos, M.R.; Castellvi, S.; Dalmolen, S.; Tsiakas, K.; Itsios, P.; Mariolis, I.; Giakoumis, D.; et al. A Security Analysis of European Data Space Architectures. *Data Sci. Eng.* **2025**. [CrossRef]
19. Sullivan, C.S.; Gemtou, M.; Anastasiou, E.; Fountas, S. Building Trust: A Systematic Review of the Drivers and Barriers of Agricultural Data Sharing. *Smart Agric. Technol.* **2024**, *8*, 100477. [CrossRef]
20. Ottmann, T.; Steinhorst, S. Data-Driven Business Model Development: Challenges and Recommendations for Action. Designing Business Model Innovations in Data Ecosystems for the Agricultural and Food Industry Using the Example of the Agri-Gaia Research Project. *Berichte Über Landwirtsch.* **2025**, *103*. [CrossRef]
21. Farina, G.; Kocian, A.; Brunori, G.; Chessa, S.; Lai, M.B.; Nardi, D.; Schifanella, C.; Bonura, S.; Masi, N.; Comella, S.; et al. Interoperable Traceability in Agrifood Supply Chains: Enhancing Transport Systems Through IoT Sensor Data, Blockchain, and DataSpace. *Sensors* **2025**, *25*, 3419. [CrossRef] [PubMed]
22. Di Bitonto, P.; Magarelli, M.; Novielli, P.; Romano, D.; Diacono, D.; de Trizio, L.; Mariano, A.; Zoani, C.; Ferrero, R.; Manzin, A.; et al. From Data to Nutrition: The Impact of Computing Infrastructure and Artificial Intelligence. *Explor. Foods Foodomics* **2024**, *2*, 810–829. [CrossRef]
23. European Commission. *Towards a Common European Data Space*; European Commission: Brussels, Belgium, 2018.
24. European Commission. A European Strategy for Data. Available online: https://digital-strategy.ec.europa.eu/en/policies/strategy-data (accessed on 14 May 2026).

25. Data Spaces Support Centre (DSSC). *Blueprint 2.0 for Federated and Trustworthy Data Spaces*, version 2.0; Data Spaces Support Centre: Brussels, Belgium, 2024.
26. Soininen, J.-P.; Laatikainen, G. What Is a Data Space—Logical Architecture Model. *Data Brief* **2025**, *60*, 111575. [CrossRef] [PubMed]
27. Musidlowska, M.; Frigeri, M. *The Concept of "Controller" in the Context of a Data Space (Part 1/2)*; CiTiP: Leuven, Belgium, 2025.
28. Musidlowska, M.; Frigeri, M. *Navigating Accountability Principle: The Concept of "Processor" in the Context of a Data Space (Part 2/2)*; CiTiP: Leuven, Belgium, 2025.
29. Casarosa, F.; Gennari, F. Data Sharing in the Internet of Medical Things: Between the Data Act and the EHDS. *Eur. J. Risk Regul.* **2025**, *16*, 1115–1137. [CrossRef]
30. Atik, C. Horizontal Intervention, Sectoral Challenges: Evaluating the Data Act's Impact on Agricultural Data Access Puzzle in the Emerging Digital Agriculture Sector. *Comput. Law Secur. Rev.* **2023**, *51*, 105861. [CrossRef]
31. Spanaki, K.; Karafili, E.; Despoudi, S. AI Applications of Data Sharing in Agriculture 4.0: A Framework for Role-Based Data Access Control. *Int. J. Inf. Manag.* **2021**, *59*, 102350. [CrossRef]
32. *Codice Civile Italiano Art. 2188*; Registro Delle Imprese; Royal Decree; No. 262. Gazzetta Ufficiale della Repubblica Italiana: Rome, Italy, 1942.
33. *Regulation EC No 852/2004*; Hygiene of Foodstuffs. European Parliament and the Council of the European Union: Brussels, Belgium, 2004.
34. *Decreto Legislativo, n. 193*; Attuazione Della Direttiva 2004/41/CE Relativa Ai Controlli in Materia Di Sicurezza Alimentare e Applicazione Dei Regolamenti Comunitari Nel Medesimo Settore. Gazzetta Ufficiale della Repubblica Italiana (Official Gazette of the Italian Republic): Rome, Italy, 2007.
35. Decreto Legislativo 62/1999. Istituzione dell'Agenzia delle Entrate. Gazzetta Ufficiale della Repubblica Italiana, Rome, Italy, 1999. Available online: https://www.gazzettaufficiale.it (accessed on 14 May 2026).
36. Legge 11 giugno 1990, n. 233. Riforma dei Trattamenti Pensionistici dei Lavoratori Autonomi. Gazzetta Ufficiale della Repubblica Italiana, Rome, Italy, 11 June 1990. Available online: https://www.gazzettaufficiale.it (accessed on 14 May 2026).
37. Tedioli, F. Il Fascicolo Aziendale: Disciplina Giuridica e Aspetti Operativi (Prima Parte). *Dirit. E Giurisprud. Agrar. Aliment. E Dell'ambiente* **2025**, *2025*, 1.
38. Decreto Legislativo 18 luglio 2018, n. 74. Riorganizzazione Dell'Agenzia per le Erogazioni in Agricoltura (AGEA) e Riordino del Sistema dei Controlli nel Settore Agroalimentare. Gazzetta Ufficiale della Repubblica Italiana, Rome, Italy, n. 166, 2018. Available online: https://www.gazzettaufficiale.it/eli/id/2018/07/18/18G00104/sg (accessed on 14 May 2026).
39. Jouanjean, M.-A.; Casalini, F.; Wiseman, E.G. Issues around Data Governance in the Digital Transformation of Agriculture. *OECD Food Agric. Fish. Pap.* **2020**, *146*, 1–44. [CrossRef]
40. Wiseman, L.; Sanderson, J.; Zhang, A.; Jakku, E. Farmers and Their Data: An Examination of Farmers' Reluctance to Share Their Data through the Lens of the Laws Impacting Smart Farming. *NJAS Wagening. J. Life Sci.* **2019**, *90–91*, 1–10. [CrossRef]
41. Bacco, M.; Kocian, A.; Chessa, S.; Crivello, A.; Barsocchi, P. What Are Data Spaces? Systematic Survey and Future Outlook. *Data Brief* **2024**, *57*, 110969. [CrossRef] [PubMed]
42. Ministro Dell'Agricoltura, Della Sovranità Alimentare e Delle Foreste. Decreto Ministeriale del 23 Dicembre 2022, Articolo 11, Comma 4. Gazzetta Ufficiale della Repubblica Italiana, Rome, Italy, 23 December 2022. Available online: https://www.gazzettaufficiale.it (accessed on 14 May 2026).