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Ownership, Control, and Governance of the Benefits of Data for Food and Agriculture

A Conceptual Analysis and Strategic Framework for Governance

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Executive summary

This study analyses the ownership, control, and governance of the benefits of data related to food and agriculture. It covers genetic information derived from crop germplasm as well as other data from and/or for e-agriculture, also known as digital agriculture, precision agriculture, or smart farming. A key point is that the data governance challenges for gene sequence information are often discussed separately from data governance in e-agriculture, but the core issues are fundamentally related. Connecting policy debates about digital sequence information with developments in e-agriculture more generally can improve food and agricultural data governance overall.

This study therefore analyzes legal mechanisms of ownership, including intellectual property rights; it synthesizes existing knowledge on this topic and provides examples of the application of these rules to different kinds of specific food and agricultural data. It also analyzes technological and social mechanisms through which data control is achieved, such as the controls over collection, storage, curation, access, sharing, and use. The study reviews, synthesizes, and analyzes the various options for data licensing and contemporary policy proposals for benefit sharing. It maps and critically assesses emerging principles and models of open data governance, such as the “FAIR” and “CARE” principles.

Section 1 of the study provides context, highlights themes, and reviews existing research on data-related concerns in agriculture around unbalanced value chains, data and knowledge asymmetries, and concentration of power, monopolies, and unfair trade practices. These concerns call for increased scrutiny of ownership and control over the access to and use of agricultural data, and who is entitled to the value or benefits associated with the use of those data. Section 1 highlights opportunities for leveraging open data for faster and sustainable innovation in agriculture, such as enhancing transparency, accountability, and efficiency across organizations. These opportunities can be leveraged to promote equity and are connected with concrete legal and policy issues associated with agricultural data ownership.

Section 2 of the study maps data ownership and explains how the law of data ownership is less ambiguous than it might seem. Data *are* owned, and those ownership rights *are* exercised. Whether and how that *ought* to be the case is debatable. An ownership approach to agricultural data raises significant concerns about the ability of all stakeholders, especially smallholder farmers, to benefit optimally from digital innovation in agriculture. But ownership and control are the status quo, and they are the reality irrespective of whether they are desirable. Moreover, accepting that extensive de facto ownership or control rights exist, we move on to consider how value-adding activities are governed in imperfectly defined normative settings. This occurs principally through contractual arrangements underpinning multilateral data sharing (open approaches) or bilateral trade in data (closed approaches).

Section 2 then reviews various data licensing practices. Subsection 2.2 builds upon the legal conceptual examples presented in the previous subsection, focusing less on what is possible and more on what is happening. Notably, the analysis addresses the case of plant genetic resources for food and agriculture as a sub-sector of biodiversity for food and agriculture, one where open data and equity issues are prominent and where international debate over one category of data – that is, genetic sequence data – is occurring. This limits the scope of the study to one key component of food and agricultural data governance and provides useful differentiation from the work of other organizations on data and/or biodiversity more broadly.

Section 3 proposes a conceptual and strategic framework for engagement with data management and governance. While declaratory actions such as charters and pledges, or licensing frameworks such as models or templates, are intriguing and important, these are not the key issue for international organizations. Instead, this report identifies three specific legal/policy challenges in respect to digital agriculture. These challenges are relevant to any organization that performs multiple roles as (a) a user, creator, and broker of data; (b) a provider of advisory services and technical assistance to its Member States; and (c) a provider of normative leadership – as is the case for the Food and Agriculture Organization of the United Nations with the International Treaty on Plant Genetic Resources for Food and Agriculture (the Plant Treaty) and its Multilateral System of benefit sharing.

Subsection 3.1 addresses the organizational roles of user, creator, co-creator, and broker of data, and their ethical implications and expectations. This subsection prepares the groundwork for potential data policy development. Subsection 3.2 addresses the organizational role of an advisor and assistant to Member States by supporting and scoping issues and contexts for more effective delivery of technical assistance on data governance law and policy. Subsection 3.3 addresses the normative leadership in the Plant Treaty vis-à-vis all other actors in the access and benefit-sharing (ABS) regime complex. This subsection considers how organizations in this space can adjust to the disruptions of digital agriculture and expand their normative functions to other relevant areas of data governance.

Overall, the report presents the case for convergent global policy and normative innovations aligned to the reality of open science and the role of big data in the push towards a reimagined ABS landscape. The conceptual framework, modelled by the open, Multilateral System of benefit sharing in the Plant Treaty, is identified as the most viable – if not inevitable – path forward for an inclusive and sustainable global regime of data governance. This model illustrates a framework with potential for adjustment, adaptation, or scaling for more inclusive exigencies of open science, digital gene sequence data/information, and a new landscape of benefit sharing on a global level that is inclusive beyond plant genetic resources for food and agriculture.

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Acronyms and abbreviations

ABS	Access and benefit sharing
AHTEG	Ad hoc technical expert group
AI	Artificial intelligence
ATP	Agricultural technology providers
BSF	Benefit-sharing Fund
CARE	Collective benefit, authority to control, responsibility, and ethics
CBD	Convention on Biological Diversity
CGIAR	Consultative Group on International Agricultural Research
CODES	Coalition for Digital Environmental Sustainability
DSI	Digital sequence information
EU	European Union
FAIR	Findable, accessible, interoperable, reusable
FAO	Food and Agriculture Organization of the United Nations
FPIC	Free, prior, and informed consent
GDPR	General Data Protection Regulation
GFAR	Global Forum on Agricultural Research and Innovation
GLIS	Global Information System
GODAN	Global Open Data for Agriculture and Nutrition
GR	Genetic resources
GSD	Genetic sequence data
IARC	International Agricultural Research Centre
ICT	Information communications technology

INSDC	International Nucleotide Sequence Database Collaboration
IPDA	International Platform for Digital Food and Agriculture
ITU	International Telecommunications Union
LIFDCs	Low-income food-deficit countries
MLS	Multilateral System
MTA	Materials transfer agreement
NGO	Non-governmental organization
OECD	Organisation for Economic Co-operation and Development
PGRFA	Plant genetic resources for food and agriculture
PIP	Pandemic Influenza Preparedness (Framework)
R&D	Research and development
SDGs	Sustainable Development Goals
SMTA	Standard Materials Transfer Agreement
TRIPS	Agreement on Trade-related Aspects of Intellectual Property Rights
UNCLOS	United Nations Convention on the Law of the Sea
UNDP	United National Development Program
UNEP	United National Environmental program
UNWDF	United Nations World Data Forum
WFO	World Farmers Organization
WHO	World Health Organization
WIPO	World Intellectual Property Organization
WIPO-IGC	WIPO Intergovernmental Committee on Intellectual Property, Traditional Knowledge and Folklore

Introduction

Societally we should aim to make the effective use of data as accessible as electricity. It is not an easy task. But with the right approach to sharing data and the right support from governments, it is more than possible for the world to create a model that will ensure that data does not become the province of a few large companies and countries. Instead, it can become what the world needs it to be – an important engine everywhere for a new generation of economic growth [1].

Numerous international agencies are developing agendas on digital agriculture or the use of digital technologies in different stages of the agri-food value chain [2], and are refocusing towards promoting technology-intensive and sustainable innovation. For example, via its e-agriculture initiative, the Food and Agriculture Organization of the United Nations (FAO) has been proactive regarding outreach and reality assessment in developing countries, capacity development, good practices, blogs, webinars, and other knowledge-sharing activities. Numerous FAO studies on "e-Agriculture in Action" touch on cutting-edge topics such as drones, blockchain, and more. FAO is also launching a platform for digital food and agriculture to provide a multi-stakeholder mechanism to facilitate discussions and leverage insights.

FAO has also led the global policy and normative agenda on genetic resources for food and agriculture for decades and hosts the International Treaty on Plant Genetic Resources for Food and Agriculture (the Plant Treaty). Advisory and policy/norm-setting activities require structured legal and policy analysis of the different forms of ownership and control of agricultural data. FAO, as a global policy and normative leader in governing food- and agriculture-related genetic resources and in promoting digital agricultural innovation, specifically in relation to crop germplasm (including germplasm managed under the Plant Treaty), is naturally engaged in this topic. This study therefore aims to provide thought leadership on the three practical issues described below.

First, for all organizations working to adapt quickly to our digital age, the challenge is how to manage technology in sync with the rapid rate of innovation in a way that enables the widest reach possible. As digital technologies are deployed more frequently, organizations are finding themselves as creators, users, and brokers of data. These roles require familiarity with the now-standard discourse around things such as the integration of meteorological or commodity-pricing data into on-farm decision-making, or the collection of data by smart farming equipment. Yet data-driven agriculture also means capitalizing on breakthrough techniques leveraging artificial intelligence (AI) in the fields of genomics and proteomics. It involves digital imaging of plant phenotypes and bioinformatics applied to rhizosphere microbiomes. As genetic resources with DNA are being dematerialized and shared beyond borders, all sectors of society need policies and principles to ensure ethical access to the benefits of food and agricultural data, while respecting ownership rights as appropriate.

A second suite of practical issues concerns the roles of international organizations as multilateral providers of technical assistance to national governments and other stakeholders. The international community will increasingly demand advice and assistance on legal/policy issues associated with digital agriculture. Fulfilling these demands will require adapting data governance law and agricultural digital service law to the fast pace of technological innovation in ways that support novel analyses and collaborative problem-solving. Data ownership is central to such demands. There is likely to be a growing need for advisory services on the interfaces between data and intellectual property rights, laws relating to the provision of digital agricultural services of various ramifications, and domestic data governance policy frameworks. An outcome of this study can be better preparedness of those developing digital agriculture policies to grapple with communities' evolving needs. Thus, this study contributes in part to the ability of advisers to provide legal information, develop legislation, and offer assessment and review tools for strengthening sustainable production in food and agriculture in ways that support trust, fairness, responsibility, respect, caring, citizenship locally and globally, and the needs of a growing population.

A third purpose of this study is to enable greater collective intelligence to support leadership roles in relation to the global norms and policies governing digital genetic resources for food and agriculture. The study will contribute to the policy and legal research portfolio that the Secretariat of the International Treaty is developing to facilitate innovative governance solutions for crop data based on the Multi-Year Programme of Work of the International Treaty. This includes continuous consideration of the impact of genetic sequence data on the objectives of the Plant Treaty. The data-intensive scientific and technological changes in which open data are nested are equally important for achieving the operational mechanisms of the Plant Treaty. Future possible normative activities may align with such reorientation to harmonize policy with technology and science while enabling fairness, considering developing country realities, and bridging divides.

Key provisions of the Plant Treaty were designed for, and premised on, physical genetic resources – that is, materials transfers. Legal and policy distinctions – for example, among in situ and ex situ activities – easily break down in a digital environment. Access and benefit-sharing (ABS) systems are strained in dealing with digital prospecting. Early orientation towards ABS is shaken by this new technological dynamic in ways that raise urgent imperatives for fairness, sustainability, and developing countries' realities, especially regarding smallholder farmers in local communities of the Global South, who are critical for feeding much of humanity.

Without policy catching up to technology and science, the reinforcement or even aggravation of existing socioeconomic power structures and inequities will accelerate. Perpetuating status quo policies and textbook approaches to ABS undermines the progress of the past several decades, exacerbates inequities – including greater gender inequality and marginalization of Indigenous Peoples and smallholder farmers – and escalates wealth disparities while fuelling distrust. Governance of crop germplasm cuts across policy debates about innovation in plant breeding; mitigation and adaptation to climate change; the urgent needs for ecosystem restoration driven by agrobiodiversity; recognition of tensions in data ownership and governance dynamics; the case for Indigenous Peoples' data sovereignty; and other multifaceted matters.

There is an opportunity for global leadership in digital and data-driven agriculture, where certain organizations are especially well suited to engage. For example, FAO's central role in the ABS international governance system, corresponding commitment to the Sustainable Development Goals (SDGs), agrobiodiversity through gene banks, strategic organizational objectives in relation to agriculture, and inclusiveness of perspectives from the Global South, all combine to make it a natural focal point for this topic. FAO's record of accomplishment in policy innovation and normative leadership via the Plant Treaty further supports its natural positioning at the forefront of this field. While the fast-paced nature of developments was circumstantially slowed down by COVID-19, policymaking enthusiasm and progress are resetting with urgency as the world adjusts to living with COVID-19.

Opportunities exist to integrate or work jointly with other organizations on these topics. The Convention on Biological Diversity (CBD) has a well-advanced research and policy agenda on digital sequence information (DSI). In part, due to an active ad hoc technical expert group (AHTEG), CBD has so far been the de facto institutional leader of normative discourse over genetic diversity and genetic data. Concrete progress on new normative solutions could be imminent, potentially setting the standard for proposed harmonization amongst international governance regimes [3].

Meanwhile, the World Intellectual Property Organization (WIPO) has a recognized influence over emerging norms for governing Indigenous and local communities' traditional knowledge and genetic resources. The United Nations Environment Programme (UNEP) is working to make digital data related to sustainability more available [4]. This work has led to the launch of the Coalition for Digital Environmental Sustainability (CODES), which involves multiple partners including the United Nations Secretary-General's technology envoy's office and the United Nations Development Programme (UNDP) [5]. The United Nations World Data Forum (UNWDF) is organizing the Road to Bern with partners to advance sustainable development [6].

Outside of United Nations agencies, the World Bank has been looking at the agriculture value chain through the lens of digital transformation in support of the SDGs [7]. Groups such as the Organisation for Economic Co-operation and Development (OECD) are also springing into action on digital food and agriculture issues. And norm-making on agriculture-related data governance, such as trade secrecy and undisclosed test data protection, has shifted to mega-regional trade deals such as the Comprehensive and Trans-Pacific Partnership and the United States–Mexico–Canada Agreement, and similar bi-/plurilateral agreements being negotiated around the world.

Digital agriculture is hardly the exclusive domain of any single organization. None alone can solve the myriad of issues. A networked, multi-level approach to governance is required. To that end, it is essential to consolidate knowledge on how ownership and control of open data are attributed at present. This requires looking at existing practices and legal constructs, how such webs of ownership and control are evolving to adapt to the new research and innovation pathways, and how such evolution can be managed globally, including through policy and norm setting, to maximize the benefits of open data while addressing associated social and ethical issues.

Several existing academic, policy, and practical studies explain ownership and control of "open" data. Similarly, some studies also describe options for global regulation and associated social and ethical issues. There is a need to reappraise these options through the lens of equitable and sustainable access to genetic resources for open innovation and sustainable development in agriculture. Such a reappraisal offers a chance to reflect on the strategic policy implications of these issues and possible pathways to respond, as well as a vision to fulfill responsibilities to develop legal and normative solutions to emerging challenges. A cross-sectoral lens on inclusive innovation and sustainable development is also needed. That includes understanding how the ownership and control of agricultural data intersect with goals to end hunger and achieve food security while increasing production by around 50% to meet population growth needs by 2050. This must be done while equally promoting sustainability through climate action, ecosystem restoration, uplifting traditional knowledge, achieving gender equality, empowering women and girls, and more.

The point of analyzing data ownership and control is not to add to the cacophony of clichés on the promises or perils of big or open data in agriculture. Far better, this study can establish a framework for legal and policy leadership in the field of data-driven agriculture. It can contribute to a normative and policy agenda for action, not just analysis.

Ultimately, the question that must be addressed, for our digital age, is this: As emerging technologies radically disrupt all aspects of food and agriculture, how do we enable legal frameworks to meet this accelerated pace of innovation while leaving no one behind? Relatedly, how can relevant organizations complement existing frameworks and support more equitable, inclusive, and sustainable global data governance?

1. The context for ownership and access to food and agriculture data

1.1 The Strategic Framework for Agricultural Innovation

FAO aims to improve agricultural productivity, nutrition, and standards of living, as well as the overall conditions of rural populations in low-income food-deficit countries (LIFDCs), while contributing to more efficient, inclusive, resilient, and sustainable agri-food systems globally. Through robust programming, FAO has continued to pursue these objectives, aiming at efficient use of agricultural resources to improve food security and sustainability. In this regard, FAO contributes to hunger reduction which has a positive impact on the standard of living for the world's most vulnerable.

Improvement in agricultural production and, by extension, the quality of food and nutrition is a complex endeavour. For all agriculture innovation stakeholders, from multilateral organizations to microenterprises, the stakes require not only alignment with the SDGs but also bending the curve on biodiversity loss, water management, and nature-based solutions for the restoration and protection of terrestrial and marine ecosystems. Those include, for example, the environment, climate, water, land, labour, sensitivity to gender, technology, and a whole set of natural resources and innumerable sociocultural, economic, political, and even technological dynamics. For example, with respect to gender, women are responsible for more than 50% of the food produced globally but remain severely undercapitalized. In sub-Saharan Africa alone, if female entrepreneurs had access to an additional USD 42 billion in funding, this could translate into increases in GDP by 2025 of USD 316 billion [8]. Bridging this gap and ensuring women can treat, access, and use data effectively could be transformational.

Taking these factors into consideration is critical for any organization operating in an international regime context with other global governance entities that have related jurisdictions and mandates. Agricultural production now entails multifaceted technology, innovation, and applications of various knowledge forms. Along with the differing cultural practices and interests across civilizations, this technical complexity must be considered in the mandates of all stakeholders wanting to take a leadership role. Bridging knowledge, information, technology, and expertise about food, sustainable agriculture, and natural resources for the benefit and uptake of LIFDCs, most of which are in the Global South, is something that FAO does and may extend to all sustainable food systems stakeholders as well.

FAO's programme on digital agriculture (also referred to as e-agriculture) represents an important initiative for capacity-building in LIFDCs that may be matched with an enabling normative ecosystem. At the heart of FAO's programming interest is its pioneering work on the management of plant genetic resources for food and agriculture (PGRFA). The institutional memory can serve the global commons by connecting efforts across time and space for more sustainable global food security and nutrition. FAO's work programme on plant genetic resources dates back to the 1980s, pursued on a complementary framework of ABS designed to address inequitable gaps regarding the contributions of world's poor to global innovation in agriculture and food production. Those efforts coalesced in the 2001 Plant Treaty.

1.2 Ownership, access, and benefit sharing

In 1992, the CBD foregrounded the critical importance of conservation and sustainable use of biological diversity – which includes plant germplasm – "for meeting the food, health and other needs of the growing world population" [9]. Conservation is an adjunct to sustainability and central to the philosophy of the CBD.

A core philosophical pillar of conservation efforts was the principle of sovereignty. By recognizing state sovereignty over genetic resources in a country's territory, negotiators established the principle upon which those resources could be governed by national laws. Conceptually, the principle of state sovereignty allowed for greater conservation efforts. Practically, it allowed countries to transform genetic resources from the common heritage of humankind into privately owned assets. Exercising their sovereignty, countries could offer ownership opportunities – for both physical specimens and the genetic information therein – to help stakeholders see and realize the economic value of nature. Of course, the concepts of cultural heritage and ownership can be interpreted very differently based on a variety of factors, including religion, gender, ethnicity, history, and more.

A corollary for pursuing the objective of conservation is “fair and equitable sharing of benefits arising from the utilization of genetic resources” [10], including plant genetic resources. Only with the assurance of benefit sharing would sovereign states be motivated to allow access to genetic resources in their territories. Well before the 2010 signing of the CBD’s Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization, the FAO’s Plant Treaty pioneered the implementation of an ABS regime, advancing its kindred relationship with the CBD.

That kindred relationship between the Plant Treaty and the CBD is clearly espoused in the former’s three objectives: “the conservation and sustainable use of plant genetic resources for food and agriculture and the fair and equitable sharing of the benefits arising out of their use, in harmony with the Convention on Biological Diversity, for sustainable agriculture and food security” [11]. Under Article 1.1 of the Plant Treaty, the objectives are to be attained by “closely linking the Treaty to the Food and Agriculture Organization of the United Nations and the Convention on Biological Diversity”.

Under the agency of the Plant Treaty, sophisticated and robust knowledge governance and management of innovations in plant genetic resources have been developed through partnerships. Most notable is the partnership with the Consultative Group on International Agricultural Research (CGIAR), under which germplasm in ex situ seed banks is conserved and distributed through the Plant Treaty’s Multilateral System (MLS) for ABS. The Plant Treaty’s model of ABS is structured as a blend of open and closed frameworks. It recognizes plants’ germplasms as global public goods and supports open access to the benefit of research and innovation arising from their use. It also allows for closed or proprietary interests under the MLS. For this, it obligates private interests that wish to exercise proprietary control over germplasm from the global seed banks to contribute a percentage of royalties to the global Benefit-sharing Fund (BSF), which is designed to support informal smallholder farmers, particularly those of the Global South. Meanwhile, the Plant Treaty continues to encourage contributions of germplasms to ex situ seed banks.

While the impacts and successes of the Plant Treaty-inspired ABS pursuant to the MLS have yet to be fully realized, the private sector’s interest in the use of intellectual property to leverage innovation in agriculture continues to intensify. This trend was fuelled by the World Trade Organization’s Agreement on Trade-related Aspects of Intellectual Property Rights (TRIPS). TRIPS subjected innovation relating to genetic resources, including plant genetic resources, to multiple layers of intellectual property via patent and plant varieties protection [12].[1] The International Union for the Protection of New Varieties of Plants complements the TRIPS Agreement, to promote plant variety protection globally.

1.3 Technological intensification towards data-driven agriculture

Technological intensification in agriculture in the last several decades has resulted in a convergence of innovations in the biological and information communications technology (ICT) realms. Through ICTs, aspects of agricultural biotechnology – especially genetic engineering and corporate convergence in the life sciences – challenge the sustainability of conventional plant breeding and, consequently, plant variety protection. The application of genetic engineering techniques results more precisely in the desired traits of plants.

The rapid pace of technological intensification in agriculture, and indeed the life sciences, has since escalated beyond conventional aspects of agricultural biotechnology and even genetic engineering. Agricultural research and development (R&D) and innovation have accelerated to the level of cutting-edge interdisciplinary applications. For example, insights from engineering, information, and digital technologies are deployed in synthetic biology to generate, modify, and generally experiment with living systems using new biological materials or parts thereof. The development of effective synthetic biology approaches, including genetic improvements, and transformative technologies directly benefits agriculture through outcomes such as productivity increases, pest management, improved crop choices, and nutritive value [13]. However, the costs of innovating and producing safe products from synthetic biology limit the entry points for low-income countries and require reflection on how to bring equity to this space.

This new world of technological possibilities in agricultural R&D and innovation is realized increasingly through data. From engineering, synthetic biology, and bioinformatics, to all other aspects of the agricultural sciences, the disciplinary convergences that drive agricultural innovation feed off one another through the agency of data. From upstream to downstream, input to output, and every step between, data create and drive value in all aspects of the supply chain. Consequently, agricultural data are now an industry within an industry. The generation, management, control, and ownership of agricultural data in their various renditions are critical for accessing valuable technology and, consequently, critical to food security.

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1 Article 27(3)(b) of TRIPS reads in part, "Members shall provide for the protection of plant varieties either by patents or by an effective sui generis system".

In agriculture, data are used to support the physical (e.g. AI-driven farm equipment), the biological (e.g. standardized crop features), and the digital (e.g. computational aspects) domains of agricultural production. A major aspect of the application of synthetic biology is that it relies on the sequencing of data from genetic resources using digital tools to replicate the whole or parts of genetic resources.

1.4 Emerging issues involving agricultural data: management and governance

Data and informatics are driving the transformation of agri-food systems, from R&D to input supply, to production, through to markets and consumption, including overcoming barriers of cost, capacity, access, feasibility, traceability, and quality. This transformation holds significant promise for smallholder farmers, especially women, who have limited access to data-driven agricultural practices despite producing a significant share of global agricultural production and safeguarding diversity in our food systems, as they have done for millennia. With increasing access to mobile technologies and improved organization and support, such as through cooperatives, they are better positioned than ever to benefit from improved seeds, agricultural practices, and decision-making support that are enhanced by emerging digital systems. This transformation also promises improved development and economic outcomes for those countries whose agricultural biodiversity underpins the increasingly interdependent global food supply and whose genetic diversity society relies on.

And yet there are fears that the full potential of a digitally led transformation to create sustainable agri-food systems and underpin conditions for achieving the SDGs may not be realized. Worse, digital technologies may further entrench rather than bridge the digital divide in agriculture, as well as escalate gender gaps. Such fears are fuelled by a ratcheting up in recent decades of unbalanced value chains, data asymmetries, power concentration, monopolies, and unfair trade practices [14]. As an industry facing multiple crises – only just beginning to confront its footprint as a key driver of biodiversity loss, climate change, and entrenched poverty – agriculture can ill afford a further deficit of trust and escalation of inequity.

Concerns around trust are compounded in the digital age, in which farm data and farmers' personal data are being generated at an unprecedented rate. Data are commodified by third parties, hungry for the innovation opportunities and commercial insights that aggregation and data mining can yield. Similarly, the genetic heritage of planetary food systems is being digitized and released into the public domain at an unprecedented rate, leading to concerns regarding the fair sharing of benefits associated with the use of this information in agricultural innovation.

These concerns – about farm and personal data on one hand, and digital genetic sequence data on the other – are escalating. They are typically discussed independently, as they arise at opposite ends of the value chain (i.e. genetic data is utilized in upstream R&D, whereas farm data is generated downstream). As we know, different data types (aggregated statistics, microdata, geospatial data, analytical research, etc.) will have to be treated differently when it comes to providing open access. However, in our view, they merit simultaneous attention as both concern the (mis)appropriation of data and ensuring a fair share of the value generated by agricultural data.

For additional context, a graphical breakdown of the data associated with agriculture is presented in Figure 1.

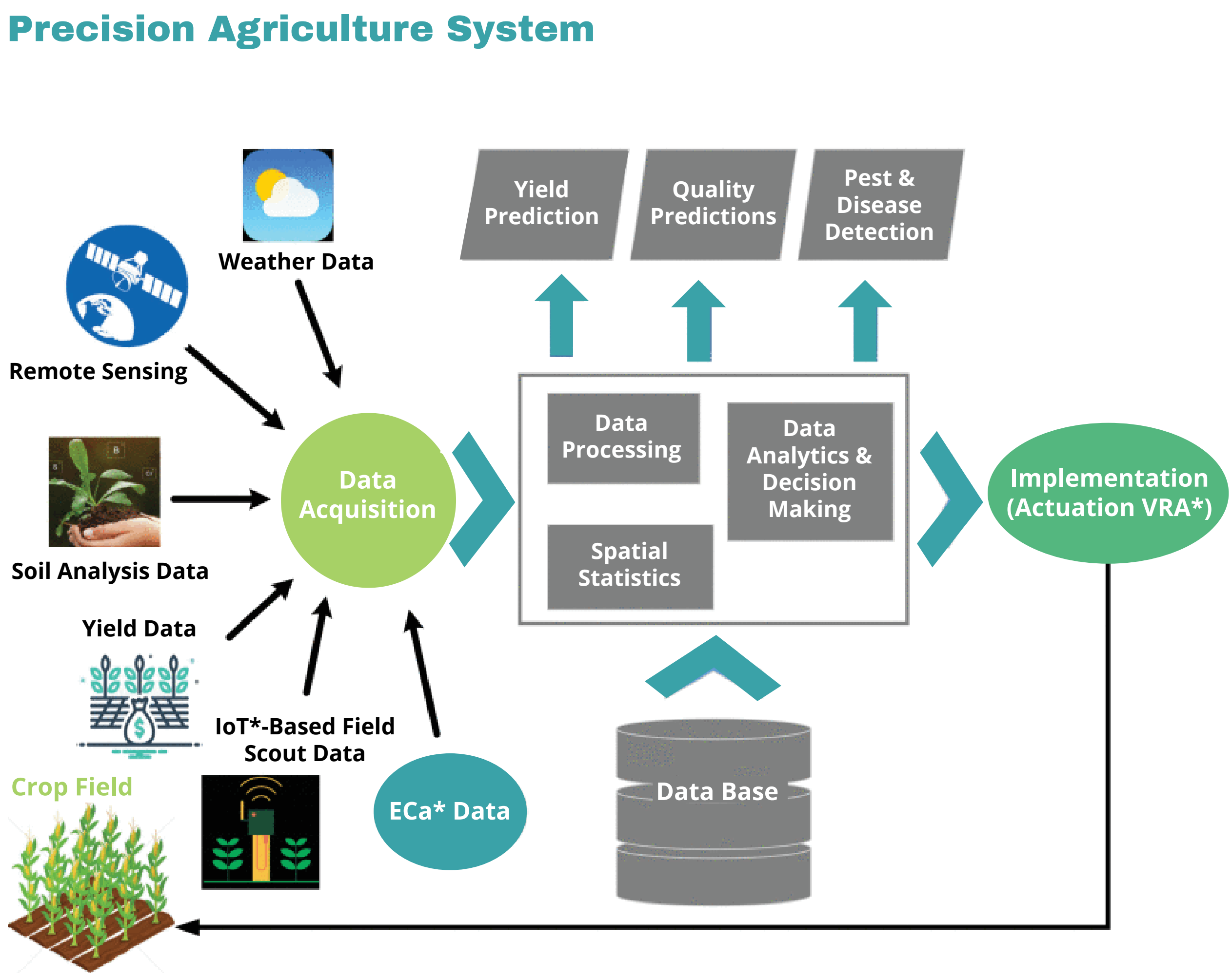

***Figure 1**: Presentation of a precision agriculture system adapted from Bhat, S. A. & Huang, N.-F. [15]. *Acronyms: Internet of Things (IoT), Soil Apparent Electrical Conductivity (ECa), and Variable rate application (VRA).*

End users such as farmers, especially rural women farmers, need to be actively engaged with other stakeholders as data producers and not as passive consumers of new technologies or field implementers of precision agriculture. Co-creating the technological future in ways that ensure fair societal and gender-sensitive benefits requires their presence. This is not just about protecting them from harm but about engaging them to ensure that they are involved in the visioning of data-driven agricultural technology to benefit them and help sustain food production globally. This sense of ownership is important for trust to enable collective innovation for grounded, informed, and deliberate choices [16].

How we provide the opportunity to integrate the 570 million smallholder women and men farmers globally – including 250 million in Africa alone – into the digital economy is crucial. This could transform agriculture by enabling data policy agendas to promote food and nutrition security, mitigate the effects of climate change, and empower women and youth to contribute to economic growth via employment. Understanding intellectual property challenges and frameworks surrounding this space is critical in order to promote enabling policies. Informed and deliberate decision-making, as captured in Article 9.2(c) of the Plant Treaty, can yield the right policies, innovation, and investment to ensure the data ownership landscape is designed properly to provide equitable benefits to all while ensuring we can feed a growing population safely and restore biodiversity through more sustainable practices [17].

Full scaling will require attention to existing agriculture divides, including digital, gender, rural–urban, and other divides. Preconditions to digital transformation include access through the availability, connectivity, and affordability of ICT. Adoption requires promoting digital skills for an agri-entrepreneurial innovation culture that is supported by a favourable landscape for data flow that benefits all while ensuring rights and access are balanced [18].

Tensions concerning appropriation are evident in the contrast between free access to data as an essential precondition to research, and access control through an extension of the current regimes of free, prior, and informed consent (FPIC) and mutually agreed terms that apply to genetic resources. Such tensions are equally apparent in regimes safeguarding privacy and enhancing the agency of data subjects regarding the data they generate, including the right to informed consent.

Concerns and grievances associated with such data can be summarized as follows:

- Many farmers are concerned that they are not benefiting from the value of the data collected on their farms or from their participation in supply chains, including, for example, business insights, as well as products and services enabled by such data. This inequality is amplified for the vulnerable, particularly smallholder farmers, and mostly women.

- Many countries, particularly those that are countries of origin of plant genetic resources, consider that the ABS objectives enshrined in international treaties and national laws are being undermined by open access to genetic sequence information, which bypasses the ABS obligations that otherwise govern access to physical samples of material.
- There is a trade-off between confidentiality and data use, and the underutilization of data is equally an existing challenge due to capacity constraints at the national level. Additionally, the promotion and adoption of open data principles alone will not guarantee better outcomes for smallholders. In fact, the open distribution of increasingly large and complex new data sources may exacerbate the productivity gap between small and large farms.

1.4.1 Trust and data sharing

As data take on greater importance in agriculture, agricultural technology providers (ATPs) [19,20] are not only selling products but also engaging in data collection and aggregation that can give them competitive advantages. By providing real-time, precision-agriculture services through automated agricultural equipment, ATPs can identify insights that they could use to drive their dominance in food production systems. For example, remote sensing equipment can offer advice on seed planting density, fertilizer, herbicide, and pesticide needs based on soil characteristics, monitoring of pests, weeds, and yield. This can help reduce input costs to farmers, increase the sustainable use of inputs, or guide ATPs to price inputs to maximize profits [21]. Power lies with whomever owns the data, controls how they are used, and decides which parties have access. How do we ensure that farmers retain appropriate rights to data gathered on farms while also anonymizing data sets to protect farmers from misuse? Issues of privacy and competition can become problematic when decisions are made through AI controlled by technology providers [22].

Farmers are made vulnerable by the absence of legal and regulatory frameworks that empower them to collect, control, share, and use agriculture data. Smart agriculture technologies are surfacing issues of data ownership, privacy, benefit sharing, trust, transportability, and accountability. Before returning to the farm as services, farm data flows go from the farm through many other actors, including extensionists, farmers' associations, financial service providers, government agencies, or others [23]. Surveys by Wiseman et al. revealed that farmers lacked trust in providers' data collection and data use.

Translation of these data within legal and regulatory frameworks highlighted five key areas of concern to farmers:

- Need for transparency related to terms of use in data licences
- Ownership and sharing of data
- Concerns related to privacy
- Asymmetry in negotiating power
- Absence of benefit sharing between the data contributors (i.e. farmers) and the data aggregators (i.e. the ATPs)

Addressing these concerns is critical to create a level playing field for farmers to be willing producers of shared data. However, is it important to note that “the recent expansion of privacy laws has been more effective in highlighting the responsibilities that data aggregators have in relation to the data they manage” [24]. The same is true of attempts at streamlining languages, taxonomies, and technological and governance strategies for interoperability and efficiency in access and use of databases. Equity requires greater access to tools and knowledge to ensure farmers are negotiating from a place of power.

1.4.2 Implications for data management and governance

New technological possibilities have two interrelated ramifications for organizations with stakes in data governance. One set of issues relates to the management of data: what practices will stakeholders use to manage the data they generate, collect, disseminate, and/or use? Another relates to governance: what rules will support or constrain stakeholders’ choices about how to treat data?

On the first issue of management, the dematerialization of genetic information is increasingly influencing the open data and open science movements. This enhances the need for guiding principles and best practices for data management. The world is awash with ideas for data management, from model licences to certification schemes to codes of conduct [25]. Successfully implementing and scaling up any of these requires an approach rooted in principle.

For example, the acronym FAIR designates the idea that data need to be easily findable, accessible, interoperable, and reusable. FAIR, however, has provoked a countervailing response from the world’s Indigenous Peoples and their local community counterparts. They express misgivings over FAIR’s focus on the big and open data movement, which they perceive to disregard their interests in data. These interests are expressed as "Indigenous data sovereignty" [26]. Indigenous Peoples insist on CARE principles for Indigenous data governance [27] as a balancing approach to FAIR. As a counterbalance, CARE stands for collective benefit, authority to control, responsibility, and ethics.

Figure 2: *The "FAIR" and "CARE" principles of data governance*

Alongside tendencies towards sui generis proprietary protection for data, the FAIR and CARE dynamics provide insights into the normative nature of data control in agriculture. Management issues arise across the spectrum of agricultural data: for "upstream" data generated by or used in the process of plant breeding, such as genetic sequence data, as well as "downstream" data from, for, or about agricultural activities, such as meteorological patterns, soil microbial conditions, crop yields, environmental factors, farm equipment operations, or commodity pricing.

A second ramification of dematerialization, one related to policy and governance, concerns the provenance and physical nature of genetic resources. The CBD, the Plant Treaty, and, more recently, the Nagoya Protocol on ABS, were individually negotiated and designed around physical access to corporeal, as opposed digitally sequenced, genetic resources for the purpose of ABS. This was at a time when the "Doomsday Vault" – the Svalbard Global Seed Vault – was a headline-grabbing idea.

An argument can be made to support flexible interpretations of these instruments to apply in the digital context. However, as classical textbook fact, law and policy tend to lag behind the rapid pace of technological evolution. And, as a practical matter, the MLS for ABS through the Plant Treaty, CGIAR consortium, and related institutions and processes is premised on physical access to ex situ PGRFA in the global and other seed banks.

As agricultural data and PGRFA continue to be reduced into virtual intellectual assets, there is pressure to shift the ABS jurisprudence and policy as we know it. Coupled with its potential to advance FAIR principles as the first logic of big, open data, digitization expedites the de-linking of valuable genetic resources from their provenance in Indigenous or local communities. The prospects of bypassing Indigenous peoples and local communities renders nugatory ABS and its *raison d'être*, warranting the need to avoid alienating Indigenous peoples and local communities as conservers of biodiversity and custodians of local knowledge. The interests, roles, and contributions of local and smallholder farmers, especially women, of the Global South in sustainable agriculture are crucial for norm setting to realize any mandate emphasizing inclusion.

1.5 Intergovernmental initiatives and policy developments

So far, the CBD appears to have seized on the legal vacuum in its treaty and protocol texts regarding digitization, ABS, and associated matters. In 2018, it expressed concern, among other things, over "increasing generation and use of digital sequence information on genetic resources, its publication in both public and private databases and advances in data analytics" [28]. The CBD has since established its AHTEG on Digital Sequence Information on Genetic Resources

[29]. The AHTEG's work aims at providing conceptual clarity on the scope of application, ABS ramifications, and other aspects of digitized genetic resources. Discussions at the CBD have coined the de facto leading terminology "digital sequence information" – or DSI for short – even though experts emphasized that this term was merely a placeholder [29] (see also [30]). Though action was mostly paused during 2020 and 2021 due to the COVID-19 pandemic, negotiations towards norm-making have recommenced as of 2022. Conversations at the CBD have begun to coalesce around the policy options and criteria for assessing ABS modalities [31,32]. Enthusiasm for a pragmatic multilateral approach is strong and building quickly [3].

At WIPO, negotiations are ongoing at the Intergovernmental Committee on Intellectual Property, Traditional Knowledge and Folklore (WIPO-IGC). Negotiators have grappled with the question of whether physical access to genetic resources or associated traditional knowledge is necessary for a user or inventor to disclose in the context of a patent application. In raising and debating this issue, the Committee was mindful of "the technological advances in this area", which include applications of synthetic biology and digital sequencing of information on genetic resources. While not explicitly suggesting that the invention must be based on physical contact with genetic resources, the WIPO-IGC Committee Chair's Draft Text on Genetic Resources also adopts language that could be interpreted as dispensing with physical access to genetic resources as a trigger for disclosure of the source or origin of an invention for which a patent is claimed [33].[2] So far, the WIPO-IGC remains prudently ambiguous on DSI, but it recognizes the regime complex in which DSI is explored as well as its potential to rupture our understanding of ABS and its operationalization in the future.

There is, moreover, a definite but yet-to-be defined link between digitized food and agriculture genetic resources and public health. That is why the World Health Organization (WHO) is also working on related topics under its Pandemic Influenza Preparedness (PIP) Framework. A technical working group, established under the broader PIP Advisory Group, has been working on the process for handling genetic sequence data (GSD) since 2013 [34]. Options put forward to WHO naturally reflect a number of particularities: the sequencing of influenza viruses, the context of pandemic preparedness, and the overarching goal of rapid and reliable data sharing [35]. Yet certain countries have encouraged alignment between the terms and principles being

2 Article 3 of the Chair's Text reads: "Where the claimed invention is [*materially/directly*] based on [Genetic Resources], each Contracting Party shall require applicants to disclose…" The list of terms in Article 2 provides that "'[Materially/Directly] based on' means the [Genetic Resources] and/or Associated [Traditional Knowledge] must *have been necessary or material to the development of the claimed invention*, and that *the claimed invention must depend on the specific properties of [Genetic Resource]s and/or Associated [Traditional Knowledge]*". Negotiation on Genetic Resources including the Chair's Text continues with the IGC 43 in spring 2022.

deployed at the CBD and WHO.

The normative agendas at agencies such as the CBD, WIPO, and WHO are complemented by policy development and awareness-raising activities from a growing array of other international institutions. The World Bank has been increasingly active on the topic. A 2019 report, for example, explains how digital technologies can improve food system outcomes if risks – including poor data governance and exclusion – are averted [36]. The OECD is also working on data governance. For instance, a 2020 OECD paper highlights the too-often-overlooked perspective of farmers in the digital transformation of agriculture [37].

Such analyses built upon earlier work by non-governmental groups such as Global Open Data for Agriculture and Nutrition (GODAN), which supported seminal work on the ownership of open data [38]. GODAN and its collaborators, including the Global Forum on Agricultural Research and Innovation and the Technical Centre for Agricultural and Rural Cooperation, have also examined digital agriculture issues from the specific perspective of smallholder farmers [39].

The topic of DSI/GSD has also been analyzed with support from national governments, such as the German Federal Ministry of Education and Research. Under the auspices of a project known as WiLDSI,[3] the Ministry has recently published a report seeking compromise on a solution to govern ABS and DSI [40]. In addition, specific studies or events on this topic have been undertaken, commissioned, or supported by governments from Norway and South Africa [41], the European Union and China [42], the European Commission [43], Switzerland [44], the United Kingdom [45], as well as the International Chamber of Commerce [46], and no doubt numerous others.

1.6 Review of academic analyses and thought leadership

Global thought leadership about the ownership of and access to data, including genetic information, is being driven by several respected policy experts and academic scholars. For example, debates over DSI/GSD have been helpfully informed by a series of CBD-commissioned studies. In 2010, experts at the Fridtjof Nansen Institute in Norway prepared a study on the concept of “genetic resources” [47]. In 2015, Scott, Schiele, and others identified possible gaps in the CBD’s provisions governing resources resulting from synthetic biology techniques [48,49]. Groundwork continued with a fact-finding and scoping study on DSI more specifically, led by Laird and Wynberg, released by the CBD in 2018 [50]. Laird and Wynberg’s groundbreaking

3 Or Wissenschaftliche Lösungsansätze für Digitale Sequenzinformation.

study, in turn, spun off three more in-depth analyses of particular issues. Houssen and others reviewed the concept, scope, and current use of DSI [30]. Rohden and others examined DSI in public and private databases, and its traceability [51]. And Bagley and her coauthors studied how domestic measures address DSI for commercial, non-commercial, and R&D uses [52]. Drafts of each study were made available online for review and comment prior to finalization. The AHTEG synthesized, considered, and reported on this information and various views for its March 2020 meeting [29].

As recently as 2021 there was no clear indication of whether – and, if so, how – discussion and analysis, let alone negotiations towards a normative instrument, would proceed among the Conference of Parties to the CBD/Nagoya Protocol. That changed quickly, however, with probably irreversible momentum building a multilateral approach [3]. Conceptually, this would more closely approximate the approach of the Plant Treaty than the Nagoya Protocol.

Meanwhile, in partnership with the CBD, the ABS Capacity Development Initiative has continued to explore DSI across diverse tangents, potentially contributing to the framing of DSI into the post-2020 Global Biodiversity Framework. The work of experts advising the CBD is rooted and enriched in a growing body of peer-reviewed academic literature on ABS for genetic information. Much work has emerged only within the last decade, with prescient analyses by scholars such as Bagley and Rai [53] leading the way.

While a comprehensive literature review is beyond this scope of this study, some examples shed light on the nature of relevant work. A book chapter about dematerialization and genetic resources published in 2017 [54] and another about resistance to change in the international ABS regime from 2018 [55] are examples. A thorough article on the future of information under an array of relevant instruments – the CBD, Nagoya Protocol, Plant Treaty, and PIP Framework – was published in 2019 by Lawson, Humphries, and Rourke [56]. A similarly broad review of DSI under multilateral environmental agreements was published in 2020 by Kobayashi, Domon, and Watanabe [57]. Various global governance models were also canvassed in a 2020 article, complementing a 2019 report, by Smyth and his coauthors [58,59]. By comparison, Aubry's 2019 article focuses specifically on DSI for PGRFA [60]. Recently, Oguamanam has examined the ramifications of DSI for Indigenous Peoples' and local communities' rights over their knowledge in the new ABS landscape [61], while Adler and colleagues have made the case for community self-governance on DSI benefit sharing [62].

The significant impacts of international governance of DSI/GSD on genomic technologies and scientific advances more generally is a recurring theme in the latest commentary published in high-profile outlets such as *Trends in Biotechnology*, *Nature Plants,* and *Science* [63–65] (see also

[66]). Another consistent theme in much commentary is stated succinctly in the title of a 2020 article in the journal, *Global Food Security*: "Open access to genetic sequence data maximizes value to scientists, farmers, and society" [67].[4] While there is wide recognition of social inequities related to genetic resources and their utilization, this recognition is accompanied by concerns that bilateral ABS transactions may not be the best vehicle, let alone a panacea, to resolve such issues. A 2020 chapter in the second edition of the *Routledge Handbook of International Environmental Law* calls for "a multilateral form of ABS for DSI" [68], an idea independently promoted by other experts [3] and echoes in some of the latest publications on this point [64].

Inequities of access are a prominent theme in leading publications on other kinds of food and agriculture data too – that is, not just plant genetic information. A 2019 book chapter, authored by GODAN experts, describes "the state of open data" in agriculture and highlights how "thousands of programmes and projects around the world have worked to open data" [69]. It is among the best available syntheses of insights from work going on in the development and NGO sectors.

Recent academic literature also explores topics such as smart farming for responsible agricultural innovation [70] (see also [16]), big data in food and agriculture [71] (see also [22,72,73]), the digitalization of agricultural knowledge and advice networks [74], open innovation in plant genetic resources [75], and on-the-farm automation and AI [76], to name just a few examples. Some articles, such as a 2017 literature review titled "Big Data in Smart Farming" [77], synthesize other works to identify themes and trends.

The broad body of literature covers legal rules and economic aspects of ownership [78,79], as well as practical legal tools to manage food and agricultural data such as a "commons" model [80] and codes of conduct [81], and certification schemes [82]. And, as with the topic of genetic information, peer-reviewed analyses of recent intergovernmental initiatives are now emerging in the scientific literature. One example is a 2020 journal article explaining how the "Ontologies Community of Practice" of the CGIAR Platform for Big Data in Agriculture supports quality data annotation [83]. Another is a comment in *Nature* suggesting how political, social, and economic interests have changed data from objects to assets [84].

Farmers' perspectives are becoming increasingly prominent in academic literature. For instance, one recent article empirically examines the causes of farmers' reluctance to share "their"

4 The authors elaborate: "This access [i.e. open access] may now be threatened by well-meaning policy-makers who have not consulted with the scientific community. Monetizing or creating greater regulation of genetic sequence data would create barriers to innovation, partnering, and problem-solving."

data [23]. A related issue is that big data may bring about potentially undesirable consequences, such as unethical exercises of power [19]. Trust and transparency are, therefore, crucial for benefit sharing in smart farming [85]. These issues are not unique to agriculture; they intersect with work on the big data divide [14], data colonialism [86], and data sovereignty [87].

The key conclusion from this overview of current thinking is that discussions are sharply bifurcated. There is a strong and growing body of research on digitized genetic information. And there is a strong and growing body of research on digitized agricultural data generally. But there is very little (if any) research connecting or thinking across the two topics, let alone their ramifications for ABS. More integrated and cross-cutting analysis on ownership of and access to food and agriculture data *of all kinds* and various interested implicated is warranted.

1.7 FAO's existing groundwork on genetic information and other agricultural data

The existing work of FAO demonstrates the dichotomy between analyses of plant genetic information on the one hand, and general food and agricultural data on the other.

FAO has demonstrated leadership in the domain of e-agriculture, which generally produces and uses food and agricultural data of many kinds. The e-agriculture community of practice emerged as a joint effort of FAO and partner organizations to implement Action Line C7 of the 2005 World Summit on the Information Society. ICTs are key to bridging information gaps, which is why data ownership and access issues are an important part of FAO's e-agriculture initiatives. The 10-year report on activities from 2005 to 2015 documents a diverse and robust community and lists dozens of publications – too numerous to describe here – relevant to these issues [88].

Since about 2015, or perhaps sooner, FAO and the International Telecommunications Union have collaborated to produce the *E-Agriculture in Action* series of reports. A 2016 report describes an e-agriculture strategy piloted in Asia-Pacific countries [89]. A 2017 report highlights how access to information has a great impact on community livelihoods [90]. A 2018 report deals specifically with the topic of drones for agriculture [91], while a trio of 2019 reports addresses big data [92], blockchain [93], and digital technologies in agriculture and rural areas [18]. Much of this work mirrors the topics covered in academic literature described above, but typically with a more practical focus on applications and stories of development.

FAO has also been working through the Hand-in-Hand initiative [94,95]. Hand-in-Hand works through partnerships to provide a framework that targets achieving the SDGs by empowering the poorest with data from over a million geospatial layers covering a variety of agriculture data.

In terms of plant genetic information specifically, groundwork at FAO and its subsidiary and related bodies can be subdivided into parallel but interwoven streams. One stream relates to the MLS of ABS (Part IV of the Plant Treaty, especially Article 12); another relates to the Global Information System (GLIS) (Article 17). These streams of work have increasingly converged in recent years.

In 2013 "the 'dematerialization' of the use of genetic resources" was identified as, in the words of the Secretary as reported to the Governing Body, among "the extensive changes which your Treaty must face over the next five to ten years" [96]. That realization is amongst the reasons the Secretariat commissioned a study on agricultural research through genomics [97]. At the next session (the Sixth, in 2015), an ad hoc open-ended working group was requested to consider genetic information associated with MLS materials. Developments up to mid-2017 were described in a helpful overview of activities submitted by the Plant Treaty Secretariat to the CBD [98].

By March 2017, the working group's co-chairs conveyed a note and convened an information event about the emerging issues of DSI. A key point was that genetic information from materials accessed through the MLS was, as a factual matter, being published in open-source databases, because such publication is increasingly required by research funders and scientific journals. Also, because the Standard Material Transfer Agreement (SMTA) is silent on the issue, no benefit-sharing obligations arose or, at least, were enforceable. This could pose problems in the context of broader SMTA revisions [99]. The same year, the Commission on Genetic Resources for Food and Agriculture established a work stream on DSI and requested that the Secretariat prepare an exploratory study [100].

Consequently, a scoping study was undertaken to examine the potential implications of new synthetic biology and genomic research trajectories on the Plant Treaty [101]. This scoping study was released in 2017 and presented at the Special Event on Genomics Information, held alongside the Seventh Session of the Governing Body in Kigali [102]. The authors note how dematerialization, or the separation of information from the plants that they stem from, affects key ABS principles and structural features of the Plant Treaty's framework [101]. They conclude, in summary, that plant genetic information is being mined for use in and outside of agriculture, with a high number of decentralized data libraries already existing. Use of material from the MLS beyond agriculture is outside the legal terms of the Plant Treaty and hard to enforce. Traceability is a core challenge, and the benefits of DSI are diverse. According to the authors, dematerialization erodes the ABS logic of identification, challenges the ability to monitor, creates value more from aggregation than individual contributions, is hard to standardize, and therefore greatly challenges the MLS of benefit sharing [101].

Earlier, in 2015, the Secretariat had also commissioned a background study paper on the legal status of genomics information in the context of the GLIS under Article 17 of the Plant Treaty. In November 2016, that paper was appraised by the Scientific Advisory Committee on GLIS, and a plan was made for coordination with the working group's parallel consideration of DSI issues. The expert study authored by Daniele Manzella explores how ABS frameworks may influence the GLIS, and more specifically the ability to gather and make available genomic information through it [103]. As a "first contribution", the study is limited to the ABS regimes [103]. It does not deal with legal protection of confidential information, copyright, or database rights, but correctly recognizes these are an "essential determinant of information flows and policy decisions" [103, citing 79]. The study does, however, usefully highlight linkages amongst the various FAO workstreams as well as related operations of international gene banks [103].

1.8 The Plant Treaty as an entry point on data governance

As demonstrated through various programming initiatives, FAO continues to deliver on its mandate. Perhaps the most influential norm-setting effort of FAO's various work programmes is undertaken through the 20-year history of the Plant Treaty. Most notable is the delicate balancing in the work to support the public goods aspects of plant genetic resources vis-à-vis the closed and proprietary imperative for curating innovations in plant genetic resources through the unique MLS of ABS in partnership with CGIAR. While the practical impacts of that ABS regime have yet to be fully felt, the intensification of innovation and various forms of technological uptake in the agricultural arena have exposed the centrality of data as pivotal intellectual assets in agriculture. A combination of many of these technologies – notably synthetic biology and the application of DSI – presents new challenges as well as prospects for norm setting.

Advancing sustainable agricultural productivity, food security, and standards of living for the world's poor depends on several factors. One is the historic norm-setting work of the Plant Treaty over a global public goods approach to PGRFA in the ABS Model. Another is the capacity to ramp up participation in inter-regime consultative and other capacities while taking leadership in all kindred and non-kindred forums where the disruptive effects of new technological phenomena are being explored.

Collaboration, notably with the CBD, holds strong potential for finding the right modality to update treaty instruments. New modalities may not foreclose ideas for outright renegotiation of the Plant Treaty, or a solution based on a broader protocol that addresses DSI and agricultural data across regimes, reconciling those with the international pull towards open science and big data.

The synergistic objective of the Plant Treaty and the CBD may be leveraged to pursue the balancing of big and open data with the concerns and interests of Indigenous peoples and local communities over data sovereignty.

The ability to manage intellectual assets associated with innovation in agriculture is a significant challenge but also an opportunity. It is an idea that falls squarely within the bounds of the Plant Treaty, and for which FAO can leverage nearly two decades of norm-setting experience to convene other stakeholders towards a shared commitment to serve present and future generations and ensure that all benefit from the next waves of technological disruptions.

2. Mapping data ownership, management, and access

Legal mechanisms for data ownership include copyright, database rights, patents, plant breeder's rights, trade secrets, and more [38,79,104]. Control is also exercised through technological protection measures, as well as social and cultural mechanisms such as Indigenous traditional knowledge governance.

Another form of data protection relates to privacy and related regulations requiring consent for the collection and use of certain forms of data. However, privacy-related rights are distinct from property-related rights in crucial ways. If data are owned by anyone, a compelling argument can be made that they should "belong" to the person to whom the data pertains. Whether that should be in the form of property rights or governed by another regime, such as privacy or contract law, is also debatable. The widely accepted principle is that people should have the chance to make informed decisions on the usage of their data. For this to happen, transparent information is needed, which all services and products must guarantee, and a data licence should include all information about the frequency of collection as well as the usage and disclosure of data.

Accepting, as a baseline, that extensive ownership or control rights already exist in respect to data, we can consider how value-adding activities are governed in these imperfectly defined legal settings. This occurs principally through voluntary practices and contractual arrangements underpinning multilateral data sharing (open approaches) or bilateral trade in data (closed approaches).

2.1 Legal ownership and practical access controls

The equitable use and sharing of data are impossible without first understanding how ownership and access works. Laying the foundation for a common understanding of legal mechanisms for ownership, exclusion, and protection is critical.

Intellectual property ownership can involve primary rights such as copyrights, patents, trademarks, industrial design rights, utility models, geographical indications, trade secrets, and related rights. Other forms of rights include database rights, plant breeder's rights, farmers' rights, moral rights, supplementary protection certificates, and sui *generis* Indigenous knowledge governance. As Ellixson and Griffin explain in their analysis of property rights in farm data, the rights conferred by legal ownership include possession, use, enjoyment, capacity to exclude others, transfer, consume, or destroy [78]. How should this be examined in the context of an intangible asset such as data versus a crop or other agricultural input/output?

Most legal systems do not confer a general property right of ownership in raw data. Whether data *should* have the same legal status as material commodities, to assure data can be allocated as property towards a natural person or a legal entity, is a complex and controversial normative question [104,105].

2.1.1 Copyright

Although the precise criteria of the protection of copyrights depend on the jurisdiction, protection is typically limited to an original work of authorship created independently and involving at least a modicum of creativity. Most data or collections of data do not attract copyright protection as raw data. Information or mere facts are typically not protectable subject matter under copyright law.

Copyright can serve the advancement of science and art through recognition and reward for authorship, which may include conferring ownership of rights in copyrighted work. However, developments in copyright over recent decades have strengthened rights holders' protection but not necessarily enhanced use or facilitated access under optimal terms. This can cause challenges in terms of access to knowledge and cross-border sharing of digitalized works – for example, in tertiary educational institutions [106]. Non-commercial uses for research and capacity-building require recognition of user rights to ensure the most marginalized are given equal opportunity to be empowered via the knowledge held in copyrighted works. Without this provision, the greater public's free access to creative ideas becomes constrained [105].

2.1.2 Database rights

Certain legal systems (notably those of the European Union, its Member States, and Mexico) offer distinct database protection as a sui generis right (i.e. unique rights in databases that fall short of the standard of an intellectual creation required by copyright law). This affords protection to non-innovative or unoriginal databases if there has been qualitatively or quantitatively a substantial investment in either obtaining, verifying, or presenting the contents. Database producers in the European Union, have the right, valid for 15 years, to prohibit the extraction and/or reuse of substantial parts of their databases by third parties [107].

The European Union has considered suggestions to confer rights to data producers that would be enforceable against non-contractual, third parties for their unauthorized use of data. Such a right could be modelled as a property right over data, or a defensive right equating to a protection of a de facto possession, rather than ownership [108]. Key drivers for such a right are, firstly, a concern that the current legislative framework does not provide enough protection and certainty to stimulate the continuous growth of the data economy and, secondly, that access to data, on which the whole data economy is premised, might be impeded with an inefficient implementation of the European data strategy. It is in this context that the data producer's right, exhibiting the traits of a property right, has been presented as one of the policy solutions to resolve both policy concerns, resulting in the stimulation of the data economy's growth as well as contributing to trade facilitation (see, for example, [109–112]).

The view that a new data producers' right would be a good policy idea has been debunked by the world's most credible experts (see, for example, [113,114]). Such a right would "seriously compromise" the existing intellectual property system, "contravene fundamental freedoms" enshrined in human rights law, "distort freedom of competition", "restrict scientific freedoms", and "generally undercut the promise of big data" [113]. Despite widespread warnings, the idea has not yet been entirely dismissed [111,115]. Momentum on this topic in Europe could easily spread elsewhere, thus influencing directly or indirectly normative debates in various international forums. This issue should be monitored.

2.1.3 Patents and plant breeders' rights

Patents and plant breeders' rights do not per se protect or confer property rights in data directly, but they can nonetheless limit the ability to use data related to the innovations they protect. For example, it is possible to obtain patents on products and/or processes derived from data, such as genetically modified plants and the methods to produce them. Plant breeders' rights protect new, distinctive, uniform, and stable varieties of plants. Therefore, even if copyright or other laws do not prohibit third parties from accessing or using the underlying data, the ability to make certain uses of data could be limited if data are associated with these forms of intellectual property rights.

Additionally, patents and plant breeders' rights are themselves sources of valuable data. Patents provide an important incentive to disclose information related to an invention instead of keeping it secret. Data related to an invention may be disclosed publicly in a patent application. For example, national patent systems typically require nucleotide sequence data associated with a patent to be deposited in public databases as part of the patent application. WIPO Standard ST.26 [116] facilitates the machine readability of nucleotide sequence listings, thereby improving the searchability and analytics associated with this form of open data.

Plant breeders' rights offer another method of indirect control over plant germplasm. Rights arise from information related to plant breeding techniques as provided by the breeder. National implementation of international instruments on these rights varies. For example,

> The African Model Law rejects patents for plant varieties and the wholesale adoption of the 1991 version of the International Convention on the Protection of New Varieties of Plants (UPOV). Instead, it presents a TRIPS-compliant sui generis model for access and benefit-sharing principles from the Convention on Biological Diversity (CBD), farmers' rights from the International Undertaking on Plant Genetic Resources for Food and Agriculture (IUPGRFA), and plant breeders' rights from UPOV 1978 and UPOV 1991 [117].

Coupled with its voluntary status, this African Union-led initiative has not, however, gained traction in Africa as pressure from Global North stakeholders has had a stronger influence over more rigid intellectual property regimes for plant varieties [118].

The tensions between competing and complementary interests for stakeholders are seeing accelerated scientific knowledge and policy move much faster compared to regulatory frameworks. At the same time countries bestowed with an abundance of genetic resources and traditional knowledge are not usually the ones with the technological tools to extract maximum value from data. This creates a tension between those who want to exploit natural resources and those who own and want to preserve them [58].

2.1.4 Trade secrets

In many countries, special protection is afforded at law to trade secrets – namely, information that is not generally known to the public, confers economic benefit on its holder because the information is not publicly known, and which the holder makes reasonable efforts to maintain as secret.

A trade secret owner cannot stop others from using the same technical or commercial information, if they acquired or developed such information independently through their own R&D, reverse engineering, or marketing analysis. However, the unauthorized acquisition, use, or disclosure of such secret information in a manner contrary to honest commercial practices by others is regarded as an unfair practice and a violation of the trade secret protection.

2.1.5 Regulatory data

Comparable protection can apply to confidential data generated to secure regulatory approval. In certain sectors, such as pharmaceuticals and agricultural chemicals in which product safety and efficacy is paramount, the data required for regulatory approvals are extensive and expensive to generate. Explicit protection against free riding, unfair competition, and public disclosure (e.g. through freedom of information laws) is useful as an incentive to undertake such data-generation efforts.

2.1.6 Traditional knowledge

In the context of Indigenous and local communities, cultural and legal norms governing traditional knowledge concern issues of ownership, as well as the ability to access, use, and share data. Norms governing traditional knowledge are not exclusively local, because international law establishes rights that may limit the ability to access, use, and share data. The Plant Treaty as well as the CBD and Nagoya Protocol impose on Member States an obligation to protect traditional knowledge associated with genetic resources, safeguard the right to FPIC to access knowledge, facilitate the sharing of benefits from the exploitation of that knowledge, and guarantee participation in decision-making.

Discussions at WIPO are also ongoing to set the terms of control over traditional knowledge more broadly. The WIPO-IGC, discussed above, is negotiating international legal instrument(s) on intellectual property and genetic resources, traditional knowledge, and folklore (also known as traditional cultural expressions). It is worth noting that under these treaty frameworks, and beyond, it is difficult in practice to draw clear distinctions between data, information, and knowledge.

2.1.6.1 Prior informed consent pursuant to ethics approval

In some countries, research activities involving human subjects are governed by national laws/regulations that require both the approval of the research protocol by an independent review mechanism to review and monitor risk, and the FPIC of the research participant. Such regulations commonly govern biomedical research. However, such standards are typically mirrored in institutional policies applicable to research involving human participants in other research fields. In the context of research involving Indigenous Peoples, the emphasis is on ensuring that consent *prior* to collecting data be *free*, which checks against unethical practices that exploit the vulnerability of Indigenous Peoples.

2.1.6.2 ABS and DSI

As explained in the introductory context of this study, and in more detail in section 3 below, ABS and DSI are at the heart of live and contentious issues being considered under the Plant Treaty, the CBD and its Nagoya Protocol, and the WHO PIP Framework. They are also relevant to the development of a legally binding instrument on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (BBNJ) under the United Nations Convention on the Law of the Sea (UNCLOS). While acknowledging that international consensus regarding ABS requirements in relation to genetic sequence information or other types of DSI associated with genetic resources is far from settled – including in relation to the subject matter that a working definition of "DSI", "genetic information", or another term may cover – there are certain jurisdictions that have implemented national ABS frameworks, which govern access and/or benefit sharing associated with the utilization of DSI on genetic resources, including GSD and potentially other types of data. For example, Ethiopia, Malawi, South Africa, and Uganda have included DSI within local ABS regimes [119] (see also [52]).

2.1.7 Personal data rights/protection

In recent years, several jurisdictions have enshrined privacy and data protection into law or are in the process of evaluating doing so. Crucially, the relevance of such instruments is limited to circumstances involving personally identifiable data – that is, data pertaining to the identity or characteristics of an individual. In the food and agricultural context, the line between personally identifiable and other farm-related data is not always easy to draw. What is clear is that anonymized, delinked, aggregated data are not covered by such regulations, nor are environmental (e.g. meteorological), economic (e.g. commodity pricing), or scientific (e.g. plant germplasm) data.

Where personal information is concerned, the European Union's General Data Protection Regulation (GDPR) represents the high-water mark for data protection. It covers the collection, organization, structuring, storage, alteration, consultation, use, communication, combination, restriction, erasure, or destruction of personal data. It also has a unique extraterritorial application, imposing obligations on organizations anywhere if they target or collect data related to people in the European Union.

The law also vests specific rights to enhance data subjects' control over their personal data. Such rights include the right to be informed and to prior consent; the right of access; the right to rectification; the right to erasure; the right to restrict processing; the right to data portability; the right to object; and rights in relation to automated decision-making and profiling. While such protections are considered by many to be revolutionary, they are applicable only to directly or indirectly identifying personal data and do not apply to anonymized data or other non-identifying data generated by or concerning a data subject. As a result, the extent of control they can afford a data subject is limited.

In Africa, 24 countries have adopted laws related to use of personal data in databases. However, more countries need to address this because data from the continent are being collected and analysed by foreign organizations in a situation of ambiguous jurisdiction [120]. India, as another example, is working on a framework modelled on the European Union's GDPR [107] within its Personal Data Protection Bill [121].

2.1.8 Other agricultural data protection initiatives

Meanwhile, in the United States, leading up to the Farm Bill[5] passed by US lawmakers in

5 The primary agricultural and food policy tool of the federal government, which is renewed every five years or so and deals with both agriculture and all other affairs under the purview of the United States Department of Agriculture. In 2019, its budget was approximately USD 867 billion.

2018, the US House of Representatives' Agriculture Committee held a hearing on agriculture technology and data utilization. The absence of laws explicitly protecting farm data were noted, and the protection of farm data was considered in response to growing concerns raised by farmers associated with the growth of big data in farming. These include a lack of trust on the part of farmers, the possibility of losing control of their own data when uploading to cloud-based storage, and frustration with the complexity of the legal agreements they must sign. It was argued that farm data should be treated as equivalent to intellectual property and that farmers' trade secrets and know-how should be protected as such. The Committee also considered good data practices certification,[6] the existence of grower-owned data cooperatives, and start-up precision-agriculture companies paying farmers to access data.

Although laws explicitly protecting farm data were not adopted, these discussions are indicative of the legal and policy solutions being evaluated the world over to reinforce data producers' rights generally and for farmers specifically. Additionally, the first major anti-trust litigation concerning the potential misuse of grower data by integrators in the supply chain commenced in the United States, and concerns the deanonymization of farm-level poultry production data by integrators in the poultry industry purportedly leading to price fixing and the suppression of grower compensation [122]. A "Farm Data Code" created by Australia's National Farmers' Federation offers another example of a relevant national initiative to govern agricultural data [123].

2.1.9 Control mechanisms (access control = de facto ownership)

There are numerous technological and social mechanisms through which data control is achieved (e.g. control over collection, storage, curation, access and sharing, and use), thus amounting to a de facto form of ownership. Because data are digital, they are typically protected not only by legal mechanisms but also by technological measures. Technological protection measures may include digital tools that protect access to and/or copying of databases. These include, for example, username and password combinations, geo-blocking restrictions, and software that limits the usability of certain features such as copying or pasting. Additionally, analytical tools that permit querying/analysis of data without providing access to the underlying

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6 One example is the Ag Data Transparent Seal (https://www.agdatatransparent.com/), a paid certification for data-collecting ag tech companies, issued by the American Farm Bureau Federation. Following consultation with stakeholders, the Federation developed the Privacy and Security Principles for Farm Data, now known as Ag Data's Core Principles. These are 13 principles that lay out rules for data collection and the agreements between ag tech companies and farmers, ranging from who owns the data to how contracts should be worded and what the proper uses of data are. See also section 2.2.5 on codes of conduct, below.

data (whether to preserve privacy or commercial confidentiality) are becoming increasingly available.

Social and cultural norms are very important in rural communities and for Indigenous Peoples in terms of how data are valued and accessed in the Global South. Governance of ownership is community based. Social values such as honour, trust, and integrity carry more weight in these contexts compared to Western legal frameworks.

2.2 Open, closed, and hybrid agricultural data management models

Accepting that legal and practical controls over data exist, notwithstanding whether they are the best models to secure the interest of smallholder farmers in digital agriculture, we can move on to consider how value-adding activities are governed. This governance occurs principally through arrangements underpinning multilateral data sharing (open approaches) or bilateral, contractual exchanges of data (closed approaches). Questions arise as to whether solutions to misappropriations of data lie in legal mechanisms to protect ownership or in contractually mediated access and other governance frameworks.

2.2.1 Open access to data

Open access is sometimes understood to mean freely available, online access to digital information. However, availability does not guarantee freedom to operate – that is, that available data and/or information are free of restrictions concerning use. For example, ostensibly open data can be subject to purpose or other use restrictions. Restrictions are usually specified in a licence, such as restrictions on commercial use. Or restrictions may not be specified in the licence but may arise legally, such as being subject to patent protection, protected traditional knowledge, ABS requirements, and so on.

Discussions concerning access and control associated with agricultural data typically occur through the polarized lens of "open" versus "proprietary" approaches. Yet this simplistic dichotomy ignores the spectrum of options in between. To resolve tensions, a more sophisticated evaluation of the underlying legal conditions, infrastructure, and social norms is needed. This includes a deeper understanding of the many possible variations between the two extremes of free access and controlled, negotiated access, particularly regarding the use of data in research.

Open data must be seen within the context of open innovation more broadly. For example, open data, open science, and open education can all be seen as pillars of open innovation. Alongside access to knowledge, these pillars contribute to “open development” [124]. Furthermore, understanding open data requires familiarity with key terminology connected with innovation, science, and technology. Table 1 presents a list of some of the terms that are most prevalent in the field.

Table 1: *Key concepts and definitions related to "open" data*

Concept	Meaning
Open innovation	Distributed innovation via purposively managed knowledge flows across organizational boundaries.
User innovation	Innovation by single individual user or user firm, to use that innovation.
Open collaborative innovation	Innovation by a group of contributors who share the work of generating a design and reveal outputs openly.
Free innovation	An inherently simple grassroots innovation process, unencumbered by compensated transactions and intellectual property rights.
Peer production	Decentralized, collaborative, non-proprietary production by widely distributed, loosely connected peers.
Sequential innovation	Innovation that builds in an essential way upon earlier innovation. Also called cumulative innovation.
Crowdsourcing	A central actor outsourcing tasks to an undefined network of people in the form of an open call.
Open source	Computer software licensed on terms that meet criteria for redistribution, source code, derivative works, etc.
Open access	Knowledge or publications that are digital, online, free of charge, and free of most copyright restrictions.
Creative Commons	A non-profit organization providing standardized legal tools (licences) that enable sharing and use.

Knowledge commons	A complex ecosystem of information resources shared by a group of people subject to social dilemmas.
Public domain	Material that is not covered by, and can be spread without, intellectual property rights.

Source: De Beer (2021) and references cited therein [125].

A more nuanced understanding enables more informed discussions concerning the appropriation of data related to agriculture, whether genetic or farm related. Such discussions are often bogged down by polarized and entrenched positions, but they require the application of a social lens to ensure service to the most marginalized is not left out. That a spectrum of approaches does in fact exist provides optimism that tensions can be diffused in a manner that balances the legitimate interests of all stakeholders across the agri-food system.

2.2.2 Data sharing bound by rules

Access to data in network arrangements can span the spectrum from closed access – in which access is restricted to specific members subject to a predetermined criterion (e.g. consortia arrangements or data cooperatives) – to approaches embodying bounded openness, whereby the underlying data defaults to res nullius (i.e. property of no one). Nonetheless, access in these arrangements is bounded by terms and conditions designed to enhance efficiency and equity, to safeguard risk, and/or to prevent or regulate certain types of exploitation. This approach has been proposed as a potential modality to operationalize the Global Multilateral Benefit-sharing Mechanism under Article 10 of the Nagoya Protocol. The common denominators in these arrangements are the acceptance of terms and conditions as a precondition to the right to access and use data, and membership on a discriminatory basis (subject to vetting or criteria). This is distinguished from standard open licences, which are generic rather than tailored and which are applied to data sets that are otherwise available to the public generally.

2.2.3 Bilateral contractual mechanisms conferring exclusionary rights in data

Contractual obligations can facilitate near frictionless access (e.g. open data licensing approaches, as considered below) or they can impose confidentiality and other exclusionary requirements that achieve a level of control akin to de facto ownership. Here, we consider the latter and note that in the presence of controversial laws governing data rights and ownership, contractual approaches governing the access and use of data are the main vehicle of the data economy. The flexibility of contract law to tailor access and use obligations facilitates a broad spectrum of options concerning data.

In contrast with the legal mechanisms considered above (in which data ownership or protection is imposed by law), bilateral obligations – assumed through volition and subject to the threat of damages for breach of contract or confidentiality – operate as an effective access control, irrespective of the proprietary rights in the underlying data.

Data generated on a farm, for example, can be protected via bilateral contractual mechanisms. Formulas, patterns, techniques, and processes that can produce on-farm economic value can be protectable trade secrets. Hacking or misappropriation of this information by others would be considered a breach of trade secret law and could enable farmers to recover actual damages, a reasonable royalty rate based on the licensing of farm data, or damages from unjust enrichment by a misappropriator. Farmers could consider implementing nondisclosure agreements in situations where elements of trade secrets may be discussed confidentially, to prohibit the unintended use of data produced on farm [78].

2.2.4 Open through standard licences

In some cases, a creator, collector, or aggregator of information wants to permit certain uses of their work. Organizations such as Creative Commons[7] provide licences to enable the sharing of knowledge. Creative Commons licensing frameworks contain elements such as the following:

- Attribution (CC BY): Allows the user to use the author's work as long as the author is acknowledged.
- Attribution-Share Alike (CC BY-SA): New creations need to carry the same licence and terms as the author's.
- Attribution-No Derivatives (CC BY-ND): Guarantees the reuse of the original work for any purpose, including commercial, but the original work cannot be shared with others, even in adapted form, and credit must be given to the creator.

7 See http://www.creativecommons.org/.

- Attribution-Non-Commercial (CC BY-NC): This licence lets users remix, adapt, and/ or build on the original work, as long as it is for non-commercial purposes. Users do not need to licence their derived work on the same terms as the original work.

If applied effectively, promoting these options in the agricultural data context could give greater agency to the smallholder farmers who contribute data. A model open data licence could be used by data collectors and be supported by a certification mark and a dedicated interest organization [126].

Creative Commons are not the only such mechanism. The Open Data Commons group provides legal tools and licences to help publish, provide, and use open data, with combinations of copyright and contractual standards. These include the Public Domain Dedication and License, the Attribution License, and the Open Database License, to name a few.

- Public Domain Dedication and License: Gives the public domain the right to use the database and its content freely.
- Attribution License: Gives users the right to use the database and its content in new and varied ways as long attribution is provided to the source of the database or data content.
- Open Database License: Any use of the database must give attribution and the new version must be accessible, and all the new products made using the Open Database License should be distributed under the same terms and conditions [127].

2.2.5 Consensus mechanisms: codes of conduct

In recent years, codes of conduct have been developed around the use of agriculture data that have attempted to safeguard farmers' interests and strengthen control over the data they generate. These initiatives are driven by organizations that represent farmers, at times with the involvement of governments. Examples included the American Farm Bureau Federations' Privacy and Security Principles for Farm Data, the New Zealand Farm Data Code, the Farm Data Code in Australia, and the European Union Code of Conduct on Agricultural Data Sharing by Contractual Agreement, as well as the GODAN Code of Conduct [128]. These codes cover central issues such as terminology, data ownership, data rights (including right to access, data portability, and the right to erasure/right to be forgotten), privacy issues, security, consent, disclosure, and transparency.

While such codes are intended to engender trust and accountability, they are not legally binding nor contractually enforceable, as compared with consensus-based mechanisms. These codes are largely voluntary and are not compliance-based. Codes are a form of self-regulation that relies on the goodwill and social responsibility of industry and agribusinesses. This can make it difficult to distinguish initiatives driven by marketing and hype from those that deliver substance and effectiveness. Additionally, although they are prepared by bodies that represent farmers (typically, industry associations in developed countries), their effectiveness in safeguarding farmers' rights and interests across the full spectrum of farmer typologies is unclear, particularly so in the case of smallholder farmers. Still, even in the absence of credible oversight or enforceability, codes help build awareness around the importance of transparency in agricultural data flows, change the way agribusinesses view data, and make data producers – primarily farmers – more aware of their rights.

Codes of conduct are an opportunity to bring a tangible, understandable, and usable framework to complex agriculture data contracts. This does not minimize the need to ensure that marginalized stakeholders have the opportunity to articulate clear objectives and directions on where the agriculture data they generate can be used, whether this is of direct benefit to them or others [81]. Evaluation, administration, and certification of these codes of conduct have to take into account meaningful ethical value generation for smallholder farmers at technical and social levels.

3. Strategic considerations for stakeholder collaborations

3.1 Users, creators, and brokers of data

Explorations of agricultural data ownership and governance tend to focus on farmers and the universe of technology intermediaries, most of whom operate within the private sector. However, a multitude of other actors are involved or implicated in the data-driven technological intensification in agriculture. By virtue of such involvement, these categories of actors play varied roles, including but not limited to creators, co-creators, users, and brokers of data. The involvement of such actors is linked to their status, role, competence, and other aspects of a given project. Outside of universities or research organizations, a broad categorization of such actors includes intergovernmental, independent, non-governmental, and/or not-for-profit agencies.

In addition to their common commitment to development, some are funders, partnering with stakeholders with a range of different interests. Aside from financing and facilitating crucial research and other projects, these funders are often originators of research ideas around which specific projects are constituted. Their association with projects that generate valuable data is, however, not value neutral. They have an interest in using such projects to advance their institutional mandate.

It is on the foregoing premise that we can consider the strategic role of intergovernmental organizations – such as WHO, the International Telecommunications Union, WIPO, FAO, the World Bank, OECD, and the CBD – as well as reputable national-government-sponsored development research agencies – such as Canada's International Development Research Centre, USAID, the United Kingdom's Department for International Development, the Swedish International Development Cooperation Agency, and Germany's GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit), to mention a few – as creators, users, and brokers of agricultural data.

For example, since its establishment in 1945, and as the oldest specialized agency of the United Nations, FAO is principally constituted as a knowledge network, dealing with and brokering information. FAO has several decades of experience in interfacing research with policy work, conducting research, and generating results that inform policy via the expertise of its multidisciplinary in-house team. This team includes social scientists, statisticians, arborists, agronomists, foresters, specialists in animal husbandry, livestock, fisheries, climatologists, animal epidemiologists, and, more recently, ICT specialists. All these team members engage in the collection, collation, analysis, diffusion, and distribution of data.

Yet, as a feature of complex ICT-driven technological intensification, agricultural data are only an aspect of an integrated data ecosystem. Consequently, how stakeholders create, co-create, and broker agricultural data needs to be situated within best practices and ongoing tensions regarding data governance. The overarching interest is in how agricultural data can serve public-good objectives. In the frame of a broader mandate, this can be realized when smallholder farmers, especially women, in nutrition- and food-insecure parts of the world are empowered to turn agricultural knowledge, which includes agricultural data, into life-transforming outcomes. Partnering broadly will continue to be critical in this space.

For all stakeholders dealing with agricultural data generated from institutional research, a total re-invention of the wheel is not required. At the core of global best practices in research ethics are the principle of FPIC, based on equitable power relations between all actors in the research process; the involvement and participation of research subjects and other stakeholders in the design and implementation of the research; and equitable access to benefits arising from such research. A difference, however, in agricultural and related research is that complementary actors may be constrained in terms of their objectives and jurisdictional scope. For intergovernmental organizations, having the capacity for due diligence and to observe the highest possible ethical standards, based on global best practices, is essential, especially where they are involved in jurisdictions such as developing and least developed countries with weak or non-existent research governance protocols.

3.1.1 Interdisciplinary partnerships in e-agriculture field research

Although every programme, project, or research is different, intergovernmental organizations must be proactive in their involvement in R&D in food and agriculture. For example, an organization may be involved as a funder, collaborator, partner, technical assistance provider, project initiator, concept designer, broker, and so many others. These roles may be undertaken at the interface with complex partners, including states, local communities, universities, various specialist research organizations, other development agencies within and outside of the United Nations, the private sector, and data intermediaries of various expertise and interests, as well as others that defy conventional categorizations. These roles require dealing with infinite data sets in agricultural contexts across national, regional, and local communities, and at the global scale, ranging from meteorological, epidemiological, statistical, and demographic data, to market, input, and climate data, to mention a few.

3.1.2 Divergent interests in collaborative data creation

Because of their divergent interests in agriculture, all partners may not share common interests, nor do they have a unity of purpose over data ownership or governance. To that extent, as one of many partners, no single organization has exclusive influence over the ownership or governance model of data arising from a project in which it is involved. Such is the case where the research is executed by independent entities. Ideally, other institutional collaborators and syndicators – such as universities and affiliated or non-affiliated research organizations – have rapidly emerging policies regarding the governance of data as part of ongoing ethical transformation. Similarly, Indigenous and local communities, including smallholder farmers in rural areas, are a major constituency in data governance. They have protocols around the use of data from the research projects in which they are involved.

Ensuring humanity moves beyond fragmented solutions to tapping into collective intelligence is essential, while respecting the boundaries of ownership, control, and privacy. Beyond now-customary, commons-oriented copyright notices in published studies, most funding agencies reserve the right to negotiate how the results of the research they support, including the data arising therefrom, can be used. In some cases, an organization is involved as co-financier – for example, when other entities participate through financial or in-kind contributions, including when a national government or one of its departments has a counterpart funding obligation.

As part of antecedent negotiation for participation, due diligence requires working with partners to ensure that such projects have clear data governance protocols to which all partners can agree. This can be accomplished through, for example, adjunct memoranda of understanding tailored to the specific project. Under such an arrangement, the overarching approach would align the use of data to further relevant mandates, specifically to secure the benefits of agricultural innovation for global public good, with special consideration given to improving agricultural productivity, nutrition, and the overall quality of life of the world's vulnerable rural populations in LIFDCs.

3.1.3 Reconciling FAIR and CARE principles with data sovereignty

Notwithstanding persistent dissonance, many stakeholders recognize the benefit of an open approach to agricultural data as part of the broader ecosystem of open science and open data. It supports making data freely available for analysis, verification, use, and adaptation by the scientific and research community and various stakeholders. Integration and collaboration optimize innovation and knowledge creation.

Communities of practice on open science data have galvanized around the now-famous FAIR principles. These principles outline considerations to deal with data in ways that would advance knowledge and innovation. The FAIR principles prioritize findability, accessibility, interoperability, and free reuse of digital assets, including, of course, agricultural data.

Extending the benefits of agricultural innovation to rural and the most marginalized populations requires a critical outlook on the FAIR principles. There is an acknowledged persistent mistrust among farmers in rural areas regarding various data intermediaries, including the proponents of open data and FAIR principles. The FAIR principles recognize the value in data integration, feeding into the massive data consolidation and aggregation phenomenon commonly referred to as big data. Yet rural farming communities lack the expertise, infrastructure, and capacity to harness any meaningful value from big data. Their ability to leverage FAIR data is further compounded by the digital divide. Rural and smallholder farmers, mainly women, in food-insecure regions of the world lack the infrastructure and skills to equitably participate in the use of agricultural data, even under the FAIR principles. It is logical that they have expressed reservations regarding the insensitivity of the FAIR principles to their unique interest in data, including agricultural data.

Consequently, Indigenous and local communities have articulated their interests in data under the concept of data sovereignty, which signifies their desire to control the data – for example, agricultural, health, planning, community, demographic – with which they are associated. Communities have proposed CARE as moderating principle to FAIR [27]. It is instructive that "Indigenous data sovereignty proponents are skeptical about the validity of CARE as a stand-alone set of principles, and hence they insist that there is a need for open data stakeholders, and indeed open science and big data stakeholders, to adhere to both the FAIR and CARE principles as a means of accommodating and accounting for indigenous data sovereignty" [129].

Organizations can leverage their participation in research by bridging the widening gulf between different schools of thought around data, as symbolized by FAIR and CARE and their undergirding orientations. While the case has been made for FAIR by the scientific community, CARE has yet to be taken seriously. Dismissal of CARE risks aggravating the prevailing distrust surrounding agricultural data among rural farming populations.

The acknowledged capacity of digitization in agriculture to alienate Indigenous and rural smallholder farmers is also a factor of the latter's inability to adopt digital technology and exploit big data. Trendov, Varas, and Zeng have noted that economics of scale is a critical factor to the adoption of digital agricultural technologies: Adoption is easier for users who can implement them at large scale. Small-scale farmers face a disadvantage compared to large agribusiness actors. This creates disparity between large and small-scale farmers, with a corresponding inequality between developed and developing countries. Transformative digital innovations and technologies are often not designed for the scale at which smallholder farmers operate [18] [16].

3.1.4 Measurable digital transformation – smallholder agricultural data utilization

For all stakeholders, ensuring that the benefits of data-enabled farming are not undermined by the digital divide or the enduring gender barriers facing women farmers is critical to strengthening equity. Programming, research collaborations, and partnerships involving data-driven agriculture in general could be deliberately structured to account for effective data utilization and technology uptake for smallholder rural farmers, especially women. A combination of poor e-literacy levels, lack of functional digital skills, and the high cost of critical IT infrastructure stands in the way of rural farmers' ability to benefit from or utilize agriculture data and other aspects of e-agriculture.

Meanwhile, within the exigencies of any associated programme, organizations can set short- or medium-term targets for smallholder farmers to deploy agricultural research data. This can be a scalable pilot effort to boost rural farmers' confidence on the empowering effects of data-enabled agriculture. The impact of a project may linger over time, and outcomes may transcend the control of researchers or sponsors. Nonetheless, a deliberate policy to realize the transformative effect of utilizing agricultural data by rural farmers is a confidence-building strategy for communities with reasons to be skeptical, given the digital divide.

3.1.5 Working with agricultural data as a principal creator or third-party partner

In the contexts of multiple collaborations, partnerships, and syndications with diverse actors, an organization's status as a user, creator, co-creator, and broker of agricultural data is complicated. Less intricate is a situation where a single organization is the principal generator of agriculture data in solely sponsored or controlled research. In the latter case, the ability to model an ethical standard for the handling, use, and overall dealing with agricultural data is not constrained by contractual relationships with multiple institutional parties, who may be beholden to their own research ethics and data protocols. Certainly, in situations where an entity has a sole or controlling organizational role in specific projects, its central motivation as user, creator, co-creator, and broker of data flows from its foundational mandate. That includes securing the interests of smallholder and rural community farmers as partakers in the transformative technological innovations in agriculture.

Dealing with agricultural data derived from institutional projects can be appraised from two broad strategic contexts. The first is where the institution is involved in collecting data from research participants, partners, or subjects, especially smallholder farmers. This situation raises greater sensitivity for transparency and confidence-building, necessitated by the inequity in power relations and persisting distrust of agricultural data intermediaries among rural community farmers. For example, in the process of collecting data, a United Nations member-driven organization's work with rural smallholder farmers in their local settings flows from the authority of relevant member nations through relevant ministries, departments, and agencies.

The second strategic context arises over how institutions characterize the status of the agricultural data obtained while executing research and policy work, as well as how they use such data or enable their use by third parties. As indicated earlier, there is no consensus over a global modality for governance of data. But the data commons and open data approach as adjuncts of open science and the big data movement continue to gain traction and momentum. This approach can present an attractive but false association with the entity's public goods approach to agricultural knowledge and information.

Challenges arise in both contexts. For instance, organizations having a direct legal relationship only with their own member nations may not be seen to meddle with the political dynamics between those nations and smallholder Indigenous and local community farmers. The relationship of Indigenous or rural and smallholder farming communities with organizations' member nations may sometimes be characterized by suspicion and a sense of marginalization. Such suspicions not only animate but also are signified in the demand for Indigenous data sovereignty and associated CARE principles [129]. This fraught relationship is a gap to be bridged to build capacity and convert the benefits of agricultural innovation, including the potential of digital agriculture. However, multilateral stakeholders can be positioned to encourage member nations to engage consistently with applicable guidelines, while nudging various other partners to translate such guidelines and public goods ethos into practice. In addition to data sovereignty and the CARE principles, other elements of emergent international best practices include the FPIC of those who are providing data; full disclosure of the uses to which research, including associated data, would be put; and a modality for equitable sharing of the resulting benefit.

Relatedly, in-depth analysis of the interface of data, information, knowledge, and wisdom [104,130,131] represents a level of complexity that is often avoided, save to note that agricultural knowledge or information, like other knowledge forms, have a mutually reinforcing and cyclical relationship with agricultural data. The logic of agricultural knowledge, information, and data as global public goods [132] is that they ought to be freely available for use and of benefit to all. However, as Aubry notes, "'open science' does not necessarily mean 'fair science'" [60]. When such knowledge or information is bundled into data sets, the economics of scale required – along with other considerations such as e-literacy, ICT skills, and the digital infrastructure for their efficient transformation into actionable knowledge – does not favour smallholder rural farmers or their governments. Rather, large-scale private sector actors and highly skilled data intermediaries are natural beneficiaries and exploiters of agricultural data, even those generated by development and public interest organizations.

For smallholder rural community farmers to actively participate and benefit in a public goods approach to agricultural knowledge and data, that approach needs to be complemented by deliberate incorporation of capacity-building for relevant stakeholders including local governments. Organizations can work with and support building the capacity of smallholder farmers for practical uptake, application, and translation of data-driven agriculture. They can also leverage goodwill to encourage partners and other stakeholders to do the same. This form of capacity-building need not be one-off. Rather, it can take a systemic approach, mainstreamed across layers of education, training, and skill acquisition within the agricultural value chain [23], and become part of global governance and development beyond any one organization. As indicated below, it is an important aspect of rethinking ABS.

This strategy has the potential to reconcile the undergirding rationale for data sovereignty with those of open science and its association with open data and big data. As well, it does not exclude the participation of the private sector and other categories of data intermediaries. Policy can be further detailed, with flexible options for the private sector or for-profit users of valuable resources to support the digital data analytic skills and overall capacity-building of smallholder farmers and local governments in the use of valuable agricultural data. The Plant Treaty's MLS of benefit sharing, which is delivered through the BSF devoted to smallholder rural farmers in low- and middle-income countries, provides the normative inspiration for this idea [75].

3.1.6 Data to advance sustainable food systems for better livelihoods

The governance of agricultural data could draw from best practices around openness for publicly funded research. Alleviating food and nutritional insecurity requires a purposeful and desirable use of agricultural data to empower smallholder farmers and not to further exacerbate the digital divide and their vulnerability.

Outside of established ABS and other protocols under the Plant Treaty, agricultural data must enable more sustainable food systems in ways that are not unduly constrained by the rights claims of data intermediaries, such as those arising from contracts, licensing, and data encryption. Preferably, the emphasis on the use of such data could be on negative restrictions akin to the Creative Commons' ideas. Examples of such restrictions include restrictions against the application of technological protection measures, patents, or other intellectual property claims without ABS obligations.

Other governance principles for dealing with agricultural data relate to ensuring their scalability to smallholder farmers. As well, considerations for gender – specifically the vulnerability and marginalization of rural women farmers – and sustainability may be necessary. This requires engaging with rural women farmers as active co-creators to learn about how they see challenges and opportunities, and addressing problems in ways that encourage communicating ideas and sharing information as reciprocal partners outside of power dynamics.

Given the complexities in data production, and the multiplicity and volatility of interests around data, an ecosystem as opposed to a sectoral approach to data has become compelling. Mounting complications around the nature of data and the process of its creation as a rivalrous but critical asset defies jurisprudential orthodoxy over ownership. This reality points to a culture shift and emphasis around the purposeful use of data for the principal objective of securing the interests of those who lack the capacity to optimally participate in the new data-driven technological dynamic.

3.2 Advising and technical assistance to Member States

Specialized organizations, such as United Nations agencies, provide subject-matter expert advice and technical assistance on core agriculture, food, and nutrition issues to Member States. That aspect of their work is typically complemented by such organizations' experience in providing legal regulatory and policy support to Member States for effective domestic and international regime building and norm setting at the interface of agriculture, natural resources, food, and nutrition for rural development. Partnerships with Member States often happen upon request to develop responsive legal and institutional frameworks suited to the changing landscape of technology-driven agricultural research production and development.

Some thematic issues – including law and climate change, gender equality, and conflict management over natural resources such as water – are subject areas for which support may be provided. Given the technological intensification in agriculture, the development of legal and policy frameworks around agricultural data is a cutting-edge subject, and organizations may be asked for legal, technical, and policy support with it.

However, as evident from our analysis so far, there is no set framework around data ownership, control, and governance in general. Apart from the coalescing of interests over the rationality of open science and open data, and the value of multilateral solutions in that context, existing approaches are fragmented and remain inchoate. No single entity is equipped with expertise on data governance, including agricultural data governance as an emerging phenomenon. Any organization's legal and technical support for Member States on the regulation of agricultural data would, therefore, take a principles-based approach. The endeavour would recognize ethical considerations around the digital skills deficit and information asymmetry between smallholder farmers and digital agricultural technology service providers.

3.2.1 Objective of legal regulation and scope of agricultural data

It is important to ensure that innovation in agriculture results in food and nutritional security and an overall improvement in the quality of life, especially for the world's most vulnerable. No intervention can be value neutral. The same is true of data and the process of their creation and utilization. According to Scassa, an important albeit "often overlooked feature of data is their non-neutrality" [104]. It follows that any regulatory or governance orientation to data is undergirded by some value. For any multilateral organization, support for Member States regarding the legal regulation and governance of agricultural data must have a purposive approach aligned to the organizational mandate.

In rendering technical support for and legal advice on the governance of agricultural data, there is need to clarify the scope of agricultural data. Agricultural data are inclusive of but not limited to farm data. There is no lack of attempt in framing and conceptualizing the scope of agricultural data. For example, Maru and colleagues detail two broad categories of agricultural data: on-farm and off-farm agricultural data [39].

A 2020 OECD study argues that agricultural data are “considered to include farm administrative and production data, including agronomic, farmland, farm management and farm machinery data” [37]. Notwithstanding the open-ended nature of this definition and the reference to conventional agronomy, this conception of agricultural data neglects the molecular thrust of agricultural innovation, the science of biotechnology, and synthetic biology, including genome editing in animal, plant, and broader genetic resources. These innovative approaches do not necessarily happen on farm, even though their outcomes are practically realized there. These innovations make genetic information a treasure trove of data-driven digital agriculture, and that is why we advocate for linking analyses of the DSI debate with digital agriculture and data governance more broadly.

Nonetheless, the 2020 OECD study outlines four organizing frameworks for generating and utilizing agricultural data. The first framework is data for production: production decision, adaptation strategies, automation, and farm administration. The second is data for delivery: packaging and processing, certification, market coordination, and trade facilitation. The third is data for policies and services: information policy design, innovation, R&D, and the like. The fourth is data for retail: traceability [37]. These four organizing frameworks for agricultural data are not mutually exclusive; they are conceptualized from the authors’ lens and do not represent the only attempt to map the scope of agricultural data.

Conceivably, agricultural data can be understood broadly from an upstream and downstream paradigm. Whichever organizing framework is preferred, it is necessary to support a robust understanding of agricultural data in their complexity. Part of that complexity is the symbiotic relationship between agricultural data and e-agriculture, which designates “the network of digital technologies and actors” involved in the generation and delivery of data, information, and miscellaneous services to stakeholders in the agricultural value chain including, most notably, farmers [37].[8]

8 These authors have a narrower, farmer-focused conception of digital agriculture as “the network of digital technologies and actors that support the development and delivery of information and services to farmers”.

3.2.2 Smallholder farmers' vulnerability in developing countries' agro-economy

The digital divide influences the overall asymmetry in applications of agricultural data and, by extension, the low penetration of digital agriculture in developing countries in contrast to their developed counterparts. The digital divide is part of the perennial geopolitical development gap in which developed countries have the financial, human, and technological resources to participate in cutting-edge innovation. That same development gap is reflected in digital agriculture and agricultural data.

For multilateral organizations, the gap presents an opportunity for normative influence and intervention through legal advisory and technical support to developing countries. In the digital and agricultural data dynamic, smallholder rural farmers in developing countries operate more as sources and providers of data than users of data in their often-lopsided relationship with agriculture technology companies and complex data intermediaries.

This dynamic mirrors the context for negotiating ABS over genetic resources. ABS is often simplified as a binary dynamic of producers and users of genetic resources, corresponding most evenly to developed and developing countries. That contested framework of producers and users animates the case for equitable benefit sharing over the utilization of genetic resources, to ensure that the producers benefit from the resources' utilization through R&D and various innovations under the CBD. Regarding the nature of interests in agricultural data, smallholder farmers are akin to how producers of genetic resources are construed in the ABS discourse.

As a matter of legal and policy priority, it is important to articulate the interests of smallholder farmers in agricultural data, and how best to balance those interests with those of other stakeholders. Examples include private sector agricultural technology data intermediaries, including those with interests in the technical aspects of data, such as hardware and software owners and other service providers. Other examples are governments, researchers, and international development organizations. A legal regime must empower smallholders to participate in generating agricultural data *and* benefiting from their use.

Farmers' insistence on a data "ownership" framework is often the starting point of the expression of their interest. An ownership approach to data, however, creates an acute jurisprudential conundrum. It is increasingly perceived as a less pragmatic option in comparison to frameworks focused on enhancing the ability to access, share, and use agricultural data, and to participate inclusively in digital agriculture. Ownership of agricultural data does not guarantee optimal, equitable, and inclusive use by all stakeholders [38,39]. This is more so because the value of data is derived mostly in their aggregation, where multiple layers of interests are implicated.

The difference in the agricultural economy of developed and developing countries should be of interest in providing support for *governing*, not necessarily *owning*, agricultural data. Agriculture is a technology-intensive industry in developed countries, where big corporate actors and agro-allied converging entities dominate the value chain. In developing countries, however, most farmers are smallholders. Most are women and their family members, who hold less than two hectares of farmland, on average. These smallholders need to be empowered to scale knowledge-intensive agriculture for sustainable, long-term contributions to food security, improved nutrition, and enhance climate resilience.

Contract law is the principal legal framework through which smallholder farmers and private sector technology companies, service providers, governments, and miscellaneous entities can articulate their interests in agricultural data. Clearly, the form of relationship between smallholder farmers and other powerful actors raises ethical red flags given the inequality in power relations. A legal regime on agricultural data would build on and consolidate existing best practices on the ethical principles of FPIC, full disclosure, and transparency over the use to which agricultural data may be put, clarity over who should have custody of the data, and details regarding the duration of interests in the data and their subsequent aggregation.

An agricultural data governance framework should facilitate smallholder farmers' capacity to use agricultural data. One way is to minimize the constraints imposed by third-party technology and data intermediaries. Farmers have an interest in the portability of data across software and hardware devices and across agricultural technology service providers. Similarly, farmers need the flexibility to repair data-associated or data-generating farm equipment without unnecessary constraints from the original equipment manufacturer. As a preliminarily matter, analysts categorize this as "the right to repair". In this regard, the standardization and interoperability of technical devices associated with data creation, including software and hardware, are necessary. They can be enhanced by legislation as well as by the provision of policy support for industry and trade practices.

Special consideration must be given to the customary protocols or norms applicable in Indigenous and local communities. The smallholder status of rural community farmers puts them in a weak position to deal with bigger partners. Therefore, a legislative and policy strategy of cooperative pooling of smallholder farmers would have contractual harmonization, bargaining, and administrative cost benefits. It would recognize the reality that among Indigenous and local communities, "data has community implications" [38]. Borrowing from international legal trends such as material transfer agreements or technology transfer agreements, national legislation can incorporate or reference model contractual provisions between smallholder farmers and data intermediaries.

3.2.3 Collection of data from smallholder farmers: legal and ethical due diligence

As a default, for the most part, agricultural data deal with the non-personal data of farmers. In the case of smallholder framers, however, situations arise where agricultural data, specifically farm data and the process of their creation, implicate or overlap with personal data and consequently the privacy rights of farmers. Legal and policy responses to agricultural data may do well to pre-empt situations of overlap with the personal data of farmers. It may be appropriate to defer to existing legal protection over personal information and the privacy of farmers under existing national laws, and applicable international and regional agreements.

In addition to private sector or for-profit ATPs, governments and non-profit development and research entities are also actors in agricultural data. They are involved in collecting from, and sharing with, smallholder farmers. The activities of these actors raise no less suspicion among farmers than those of their private sector counterparts. Ministries, departments, and agencies collect data ostensibly for public interest purposes, which includes a wide range of objectives. For example, they collect, use, and share data for policymaking as an incidence of their regulatory duties, which may be beneficial to farmers. In other instances, governments collect data as an act of surveillance for law enforcement, for monitoring regulatory compliance, and for intellectual property protection purposes such as patents and related rights.

The context in which public agencies operate is mediated by relevant multilateral treaties, as well as bilateral or regional trade agreements. The development of national legal regimes on agricultural data must be premised on an assessment of constraints under applicable instruments. It is within the purview of national laws to ensure that data collection is conducted in accordance with ethical principles and the rule of law. National governments are not strictly required to – but should – comply with international ethical best practices around the procurement of sensitive information or data from smallholder farmers. Sometimes, however, enforceable legal obligations exist. For example, as with pharmaceutical data, governments may extend regulatory data protection on agricultural data held by ATPs. Where such agricultural data are generated by data intermediaries from or in association with smallholder farmers, their subsequent use – for example, for regulatory data protection or intellectual property or related rights – must be disclosed in an ethically transparent manner. Not only must the data be obtained with the FPIC of smallholder farmers, but accounts must also be taken of their interests in the equitable sharing of benefits arising from the use of agricultural data in the context of regulatory data protection, intellectual property, and other uses.

In more general terms, OECD research and analysis on agricultural policy monitoring and evaluation has highlighted key policy recommendations to support healthy production decisions and markets.

Table 2 draws on and expands upon some of these recommendations [133], recasting them to particularly focus on supporting low- and middle-income countries in their development of effective agriculture data policy for smallholder farmers.

Table 2: *Recommendations for effective agriculture data policy, based on OECD key policy recommendations*

1	Enable policy incentives related to agriculture data that can help increase the productivity, sustainability, and resilience of smallholder farmers.
2	Provide sufficient public funding to ensure the availability of public data that can increase smallholder farmers' knowledge base to help them improve their livelihoods and capacity to contribute to food security sustainably.
3	Incentivize collaborations that empower smallholder farmers' capacity to take up knowledge-intensive agriculture through the co-generation of data to insights with public and private actors – locally, regionally, and globally.
4	Ensure FAIR data principles are adopted and implemented across public institutions to ensure a data-driven economy equitably serves smallholder farmers.
5	Use the full range of economic data, "including information, education, regulation, payments, and taxes", to generate insights that help smallholder farmers pursue climate- and environmentally resilient practices from the farm, through processing, to delivery to consumers.
6	"Streamline risk management policies by clearly defining the limits between normal business risks, risks for which market solutions exist or can be developed," risks related to ethical and legal use of data or absence of capacity to use data and "catastrophic risks requiring public engagement".
7	Harness digitalization to "improve understanding [and the availability of tools that support as well as help track in real time] the overall financial and well-being situation of farm households to design farm-income support measures targeting those in need."
8	"Develop coherent policy packages that can address the many opportunities and challenges confronting the sector and farm households" including the capacity to use agriculture data effectively and equitably.
9	"Shift responses to the COVID-19 pandemic from temporary relief measures towards deeper investments in the long term resilience of the food and agriculture sectors" and in the capacity to harness digitalization for sustainable food systems optimization from the farm across value chains.

Source: Adapted from OECD, quotes from [133].

3.2.4 Use of technology to bypass consent to acquire on-farm data

An unresolved issue that may be of interest for law and policy regarding agricultural data is the changing dynamic for accessing on-farm information and its ramifications for ensuring FPIC from Indigenous and local communities. Nowadays, remote sensing technologies – including satellites, unmanned aerial vehicles (i.e. drones) and many others – are used to access data in ways that bypass conventional consent procurement protocols. They may also circumvent the jurisdictional or geographical claims and authority of states and smallholder farmers. The use of these technologies can exacerbate inequities, necessitating a combination of legal and policy interventions to ensure these technologies are not used to undermine ethical best practices, including consent, and the interests of smallholder farmers and developing countries. One way to ensure that these forms of technologies are not used unethically is to support investment in physical digital infrastructure in developing countries for controlling these technologies. That could also be of interest in an inclusive and reconfigured ABS regime. Establishing shared values and ethical principles for certain technologies could become foundational to how we innovate. This would require the greater participation of marginalized communities as producers.

3.2.5 Smallholder farmers and intellectual property in agricultural data

Section 2 examined the complex intersection of intellectual property and related rights, and data ownership or governance. Here, we highlight smallholder farmers as primary sources of agricultural data. This context is important for providing legal, technical, and policy support for organizations or states on digital agriculture.

The interface of intellectual property and related rights with agricultural data validates the idea that the value of data lies in their functional application. As primary sources of agricultural data, rural smallholder farmers do not have equal leverage on all rights associated with that data. Unlike patents, copyrights, and sui generis rights over databases, smallholder farmers may be able to benefit from market-oriented aspects of intellectual property's interface with agricultural data, such as brand certification, trademarks, and geographical indications. In designing a legal framework for agricultural data, consideration must be given to the uneven importance of different aspects of intellectual property in agricultural data as they relate to smallholder farmers.

As a policy matter, it is not desirable to foreclose intellectual property rights to private sector agriculture technology intermediaries involved in the agriculture data ecosystem. Rather, it is necessary to ensure that those who seek proprietary rights in agriculture data sourced from smallholder farmers accommodate the latter in sharing the benefits, based on the expressed needs of the farmers. As with the concerns over smallholder farmers' claims to the ownership of agricultural data, it is doubtful that claims to ownership of the intellectual property associated with agricultural data could result in the optimal use of and benefits from data-driven digital agriculture.

3.2.6 Rethinking the pre-eminence of agricultural data ownership

Smallholder farmers' inclination to request ownership of agricultural data is understandable as it is premised on the lack of trust emanating from the digital skills gap and the information asymmetry that characterizes the farmers' relationship with agro-technology data intermediaries. However, based on a public goods approach to agricultural innovation and considerations for equity and ethics, it is important to question whether smallholder farmer ownership of agricultural data would advance the objectives of enhanced food security and nutrition. This is necessary because a public goods approach is aligned with and capable of catering to the interests of smallholder farmers and encouraging win–win paradigms for all stakeholders.

By nature, the value of data, including agricultural data, lies in their aggregation and ultimate translation. In sectoral and isolated forms, data have limited value. What is the use owning agricultural data without the ability to aggregate, diffuse, analyse, and expand the chain of derivation? It is only when data are aggregated or related to other data or information in a complex chain of derivation that their value to advance public goods in agricultural innovation is realized. Similarly, many actors are involved in the process of data creation, including hardware and software technology providers, who often provide the technology and information necessary to extract data from farmers. As well, despite the multifaceted range of data in agriculture, smallholder farmers' interests tend to crystallize mostly around farm data.

This last observation contrasts with the activities of many high-tech private sector agricultural actors. These sophisticated operators are involved in molecular levels of agriculture, deploying R&D insights from biotechnology, synthetic biology, genome editing, and so forth, to generate valuable agronomic data. Some of these data are generated off-farm, in laboratories. Were these actors to also insist on data ownership in the same degree as smallholder farmers, all stakeholders would face more hurdles in order to benefit from digital innovation in agriculture. Fluidity in data transmission chains call into question the rationale for an ownership approach to agricultural data. As a contemporary matter, advancements in synthetic biology and the applications of DSI uncover the interconnectedness of data across sectoral boundaries. These new technological dynamics warrant serious consideration for an ethically mediated global approach where access and utilization of data by all actors, including smallholder farmers, could serve a greater public-good outcome.

3.3 The Plant Treaty as normative model

This subsection considers how the Plant Treaty may withstand the disruptions of digital agriculture, and what policy and normative innovations might be possible or necessary.

In the execution of its mandate, the Plant Treaty is an integral part of a global effort for the conservation of biological diversity, specifically agro-biodiversity. As we pointed out, FAO has an analogous relationship with the CBD, which has advanced through the Plant Treaty. The Plant Treaty shares the three cardinal objectives of the CBD, which it seeks to translate in the agricultural context pursuant to a larger organizational mandate on sustainable agriculture and food security. Accordingly, Article 1.1 of the Plant Treaty provides that "The objectives of this Treaty are the conservation of and sustainable use of plant genetic resources for food and agriculture and the fair and equitable sharing of the benefits arising out of their use, in harmony with the Convention on Biological Diversity, for sustainable agriculture". Article 1.2 declares that the objectives of the Plant Treaty "will be attained by closely linking this Treaty to the Food and Agriculture Organization of the United Nations and to the Convention on Biological Diversity".

The CBD's focus is on the conservation of biological diversity, which is a broader concept than the focus of the Plant Treaty. However, the current technological landscape demonstrates the practical applications of digital technology and the "datatization" of information in ways that blur jurisdictional, sectoral, and disciplinary divides. The capacity of digital technology to deploy data uncovers the interdependence of concepts and the melding of disciplinary boundaries, especially in the life sciences.

Consequently, despite expressed disciplinary or jurisdictional scope, no entity or organization is capable of optimally executing its mandate except in relationship and collaboration with others. So far, the delineated focus of the Plant Treaty on "plant genetic resources relevant to food and agriculture" has been the basis of strategic norm-making aligned to the three converging objectives: conservation, sustainable use, and fair and equitable sharing of benefits arising from their use.

3.3.1 Pioneering and operationalizing the ABS process

Over the past decade and a half, the Plant Treaty has embodied institutional leadership in pioneering the first operational international scheme designed for global attainment of the shared objectives of the CBD and the Plant Treaty. The scheme is premised on an understanding of plant genetic resources – that is, germplasms as distinct from crops, per se, which are commodities or physical biological objects. The concept of plant genetic resources emphasizes information or components of actual and potential value, representing the building blocks for farmers, breeders, and all innovators involved in crop improvement for the advancement of sustainable agriculture and food security [134].

The Plant Treaty recognizes the vast range of plants' genetic diversity in their centres of origin, mainly in the Global South. Nonetheless, it is premised on the interdependence of all countries and regions of the world on plant genetic resources. In Annex 1, it itemizes a preliminary list of 64 of the world's most important plants that account for up to "90% of calories, fat, protein and weight consumed worldwide" [60]. Pursuant to the Plant Treaty, parties agree to provide, via the MLS, facilitated access to annexed plant genetic resources, in exchange for an unfettered uptake of the benefits of R&D and innovation arising from their use. The MLS contrasts with the more expensive, restrictive, bilateral, and often individualized system through which discrete countries had negotiated and exchanged specific genetic resources. It is designed to ease the flow of access to resources for farmers, breeders, and R&D entities in support of innovation and sustainable agriculture.

The Plant Treaty's MLS has in-built harmonized access forms and conditions via the SMTA as well as a global benefit-sharing scheme. Benefit sharing under the Treaty is delivered through the BSF. The BSF is managed on a fiduciary basis, to which parties to the Treaty, especially industrialized countries, are encouraged to contribute. The Treaty recognizes that intellectual property is necessary to sustain investment and innovation around plant genetic resources, especially by the private sector. But it is also mindful of both the low capacity of smallholder farmers to develop intellectual property assets and the propensity of intellectual property to undermine the interests of smallholder farmers whose traditional landraces constitute a large proportion of the annexed plant genetic resources.

Consequently, the Plant Treaty adopts a compromise on intellectual property, allowing claims over innovations associated with annexed plants, subject to willing claimants' contributing a fraction of royalties to the BSF. As part of a focus on the public goods aspects of agricultural innovation and recognition of the role of smallholder farmers in sustainable agriculture, the BSF is dedicated to supporting and enhancing their contribution. The Treaty also makes novel, albeit vague, provisions for farmers' rights, which are in need of clarification. These rights, which are undefined, aim at recognizing "the enormous contributions the local and indigenous communities and farmers of all regions of the world, particularly those in the centres of origin and crop diversity, have made and will continue to make for the conservation and development of plant genetic resources which constitute the basis of food and agriculture production throughout the world" [135].

Even though the results of the ABS framework of the Plant Treaty have yet to be fully realized, the Treaty represents the first major attempt at operationalizing the ABS scheme, ahead of the CBD's Nagoya Protocol process. Through the Treaty, relevant organizations have pioneered and led norm development on ABS.

Perhaps most importantly, the Plant Treaty's focus on resources as germplasm – the domain of species-specific genetic information – is a pioneering normative approach that is way ahead of its time. Close to 20 years after, the major conundrum around ABS is how to fix the disconnect between the physical and informational aspect of genetic or biological resources with the advent of DSI. Writing in reference to the operations of the Plant Treaty, Daniele Manzella argues that "germplasm transferred with the SMTA is under the purview of the Multilateral System, and not subject to other ABS regimes … offer[ing] initial ABS viability in terms of access to and utilization of information associated with germplasm including genomic information" [103]. Further norm building, especially under a kindred regime such as the CBD, would benefit from key institutional experience on ABS under the Treaty.

DSI is the quintessential pivot of transdisciplinary technological revolution that reifies the value of information and data on a globally iterative scale. It unravels the pivotal power of data and its mediation of information across all life sciences – food, agriculture, health, biodiversity, environment, etc. – in ways that shake existing and emergent ABS frameworks. The Plant Treaty reflects an attempt at reconciling existing tensions across geopolitical lines between R&D technology innovators and smallholder farmers who operate as stewards of plant genetic resources at the centres of origin and crop diversity. The MLS underscores the interdependent nature of plant genetic resources and the need for both open and closed systems of knowledge exploitation as well as flexible and dedicated forms of benefit sharing that incorporate capacity-building among less technologically endowed stakeholders. As a departure from the outmoded and narrow bilateral framework, the global appeal of the MLS is further enhanced through the increased pace of the applications of technology across the life sciences, including agriculture.

3.3.2 CBD's initiative on digital sequence information (DSI)

Since 2016, the CBD has led legal and policy explorations on DSI on genetic resources, exploring through the AHTEG the relevance of DSI for advancing the three objectives of the CBD. Analysts agree that DSI has the potential to advance the three objectives of the CBD. But it has the most disruptive effect on the third objective of the CBD – that is, the fair and equitable sharing of benefits arising out of the utilization of genetic resources. As described earlier in this study, DSI (also known as GSD in some circles) is a place-holding term, the precise meaning of which has yet to be determined. It involves the sequencing of DNA and RNA data from tangible materials for their functional renditions and applications across various data platforms on a global scale.

DSI makes possible the development of biosynthetic alternatives to genetic resources through synthetic biology and other data transcription applications. A 2020 CBD AHTEG study was the first institutional-driven expert attempt to map the scope of DSI strictly based on the direct flow of genetic sequence information and biological processes from the underlying tangible genetic resources [52]. The study identifies genetic and biochemical information as DSI if it is expressed in the following forms and their combinations: DNA, RNA, proteins, epigenetic modifications, metabolites, and other macromolecules. It suggests that information associated with genetic resources, DSI, and so forth, including traditional knowledge, does not qualify as DSI [29].

Based on the work of the CBD, so far, opinions are divided as to whether DSI comes under the scope of the CBD. The first school of thought is affirmative: that DSI comes within the scope and definition of genetic resources under the CBD, at least based on the CBD's spirit and intent. While this approach is clearly tenable, it raises concern regarding the definition of generic resources in the CBD, which refers to "genetic material" [10]. On its face, genetic material presumes a physical property. Also, at the time of the negotiation of the CBD, the Nagoya Protocol, or even the Plant Treaty, the practical applications of DSI and associated disciplines such as synthetic biology and "omics" in biodiversity conservation, agriculture, and related fields were not in vogue.

The second school of thought argues that DSI results directly or indirectly from genetic resources, and therefore it is not directly provided for under the CBD. A CBD-commissioned fact-finding study on the domestic status of DSI in ABS contexts shows that these two approaches are also evident in how domestic laws treat the status of DSI [52]. There is ample room for flexibility within the key ABS instruments – including the CBD, the Nagoya Protocol, the Plant Treaty, and the WHO's PIP Framework – for the definition of genetic resources to include related information in DSI. The same flexibility is reflected in national laws [56,103].

3.3.3 DSI's seismic disruptions of ABS norms

If DSI is understood as a genetic resource, then dealings with DSI will activate all ethical and access protocols, including FPIC. Also, it would require confirmation of the sources and origins of DSI as a genetic resource and the detailing of other issues relating to provenance. The second approach, which locates DSI as a *derivative* of genetic resources, automatically dispenses with access protocols and the traceability of provenance and associated limitations. Rather, it requires the emphasis to be placed on an appropriate benefit-sharing mechanism arising from the *utilization* of DSI. This approach is attuned not only to the disruptive effect of DSI but also to the operative reality of the phenomenon, which is enhanced through a globalized network of big data, where the value of a digital sequence lies in its connection to other sequences in a decentralized framework. A focus on value versus ownership also creates the opportunity to explore what benefits all stakeholders can and should receive to ensure equity regarding their capacity to contribute to scaled global and local food security and nutrition.

With the advent of DSI and its applications across virtually all life science fields (most notably in synthetic biology), it is possible to bypass physical access to genetic resources and the issues of provenance upon which rest the existing norms of ABS, such as the third joint objective of the CBD and the Plant Treaty. Perhaps the most revolutionary effect of DSI is the convergence of valuable life sciences information across all scientific and technological frameworks in both their theoretical and practical ramifications. This scientific and technological disruption intensifies similar sentiments associated with the digital divide. It threatens to obliterate the interests of smallholder farmers and Indigenous and local community stewards at the centres of global genetic diversity from the established norms of ABS under the CBD and the Plant Treaty.

DSI portends to upend decades of normative development around a public interest approach to agricultural R&D and ABS through the Plant Treaty and its relationship with the CBD. This creates a conundrum. Technology risks rendering obsolete the framework for decades-long norm-making around ABS. But DSI also presents an opportunity for the radical consideration of novel science, law, and policy options to reset the shared objectives of the Plant Treaty and CBD through the catalytic role of data-driven innovation in agriculture and the life sciences on a harmonized and, possibly, globally inclusive scale. This speaks to the need to accelerate behavioural shifts, crystallized through enabling policies that ensure that technological advancement is met by agile social frameworks that enhance the alignment of scientific progress and governance.

In a way, DSI marks progressive transformations at the interface of the digital and biotechnology revolutions. Reference is readily made to how the formerly long-drawn and costly process of sequencing human genomes and aspects of the traditional process of genetic engineering are now radically reduced and simplified in time and cost through DSI. Through DSI and synthetic biology, bioinformatics, data analytics, aspects of bioengineering designs, and omics, scientists can now collaborate at complex interdisciplinary levels to create, co-create, and even re-create existing or non-existing biological materials or parts. They can undertake genome editing and various forms of manipulations of genetic materials and their sequences – including plants, animals, and even humans – by inserting, deleting, or replacing DNA, RNA, and protein sequences. DSI is essentially a database of raw sequences: it has no real value in isolation, but its value added is in relation to its connection to other sequences along integrated and iterative pathways of scientific discovery.

3.3.4 Open science, disciplinary convergence, and global database networks

In the era of digital-driven innovation, there is a growing attraction for open access strategies and the greater intensification of open science culture. This trend feeds off a network and clusters of databases with variant access protocols and operational models aimed at supporting the tenets of open research science. Globally, the International Nucleotide Sequence Database Collaboration (INSDC) is a consortium of three leading digital databases of DNA and RNA sequences – the DNA Data Bank of Japan, GenBank (United States) and the European Nucleotide Archive (United Kingdom) [136]. The INSDC is the largest global platform for collecting and disseminating DNA and RNA databases. It has developed expertise in collection and management, including the dissemination of sequenced data across all life sciences. It serves as a premier global open data forum for scientific process and discovery on a big data scale.

The INSDC has developed a system for data validation, organization, standardization, integration, indexing, and curation. The INSDC database encourages the collection of sequences, even those associated with intellectual property such as patents that are flagged with a "PAT" inscription, for information purposes only. The interface of DSI with intellectual property evokes questions that have yet to occupy policymakers. So far, the INSDC platform supports malleable applications and uses of digitally sequenced data, making it severable and interoperable, and facilitating the flow of data across multiple clusters and networks for diverse interests and applications. In this context of the global open access framework, the possibility of DSI for scientific discovery and revolution across all life sciences is realizable. At the level of DSI, linking sequenced data to the provenance of physical genetic resources for ABS is a problematic – although not necessarily impossible – proposition. Accurately identifying and profiling the contributors of sequences and their users, determining the value added of each sequence, and distinguishing between commercial or non-commercial ramifications in research are just snapshots of the conundrum DSI presents for ABS [51].

The breadth of the applications of DSI is its greatest value. DSI enables the identification of organisms and microorganisms through DNA barcoding, thereby enhancing taxonomic development and accuracy. DSI provides information useful for stemming species extinction and makes possible the use of genetic markers for selective breeding, drug discovery, unlocking the possibilities of phytomedicine, advancing vaccine development, crop adaptation to climate change, identifying valuable soil organisms (especially microbiomes), and controlling plant disease.

In 2019, Chinese scientists were able to rapidly sequence the genome of the new coronavirus first discovered in Wuhan Province. The information was freely available through INSDC, and it enabled the invention of COVID-19 diagnostic kits and the development of the Pfizer-BioNTech COVID-19 vaccine and enabled other vaccine pathways. This demonstrates the role of DSI (referred to as GSD by the WHO) in pandemic preparedness and in tackling infectious disease-related public health emergencies. Scholars have begun to unpack the crucial importance of open access in this context [137].

As introduced above, even more so than the CBD and the Plant Treaty, the WHO PIP Framework directly references genetic sequences in the context of ABS. Article 4 of the PIP Framework for the sharing of influenza viruses and access to vaccines and other benefits specifically defines genetic sequences as "the order of nucleotides found in a molecule of DNA or RNA. They contain genetic information that determines the biological characteristics of an organism or a virus" [138]. Further, DSI shows the practical operations and possibilities of a global open data framework – for instance, through the INSDC data network. From agriculture, food security, climate change, and human and animal health to biodiversity conservation, DSI is a site for underscoring the blurring of disciplinary boundaries and the interdependence of information and data for scientific progress, the value of big data, and the transformative power of collaboration and open science for innovation, scientific discovery, and contributing to global good.

3.3.5 Digital cooperation: the International Platform for Digital Food and Agriculture

The INSDC's leadership in advancing the collaborative uptake of DSI illustrates, in a way, an aspect of the current phase of globalization in which digital technology innovations continue to enhance and deepen integration and interdependence. In this new normal, digital collaboration and cooperation are at the core of the global cooperation architecture of the United Nations. FAO, through its initiative on the International Platform for Digital Food and Agriculture (IPDA), aligns with the United Nations High-Level Panel on Digital Cooperation aiming to strengthen cooperation in the digital space through good science, technology, ethical, and regulatory policies.

The IPDA reflects an expansion of active and practical leadership on digital agriculture with initiatives such as underwriting apps that assist with extermination of invasive crop-devouring pests [139]. Other initiatives include supporting rural farmers' use of mobile phone features, promoting widespread access to geospatial data for farmers, and a new digital services portfolio [140]. This portfolio delivers sensitive information and various advisory services to smallholder and rural community farmers in food-insecure parts of the world, especially Africa.

The IPDA is a further advancement of previous extensive activism around collaboration for digital advancement and policy elaboration, as evidenced by its association with the Digital Public Goods Alliance, Artificial Intelligence for Good, and the Internet Governance Forum. As with these initiatives, the IPDA is designed as a strategic and inclusive platform for policy dialogue, comprising farmers, civil society, researchers, academia, knowledge organizations, the private sector, and others, to identify and explore the benefits and risks of digital agriculture and to map out multi-stakeholder policy advice and recommendations.

Before the formal launch of the IPDA in 2021, FAO hosted a high-level dialogue in December 2020 regarding the establishment of the IPDA. Deliberations at the multi-stakeholder forum captured robust perspectives on the benefits, risks, and ethical issues associated with digital agriculture. The forum highlighted perennial concerns about the digital divide, with the Rome-based World Farmers Organization (WFO) leading the charge. The WFO called for a "reverse paradigm" in digital innovation so that farmers can be involved in digital innovation planning, as opposed to the current top-down model [141]. According to the WFO, a farmer-driven approach to digital innovation would position farmers on a more balanced footing with technology providers in efforts to ensure that the concerns of farmers are integrated into innovation planning. WFO's hope is that the IPDA would assist in promoting global understanding about farmers' desires and their expectation from digital agriculture, while enabling inclusive deliberations by all stakeholders to support policy coherence. For the WFO, the IPDA would serve as resourceful platform or, in the words of the WFO Secretary-General, as an "enabler hub" to empower farmers' participation in digital agriculture [141].

During the high-level dialogue, participants agreed that the IPDA would advance international cooperation and knowledge sharing. In an agenda-setting tone, participants identified a laundry list of items for ethical policymaking around digital agriculture, including the role of AI. The list includes bridging the digital divide and its effects, the affordability of technologies, recognition of cultural sensitivities, human rights, environmental safety considerations, biodiversity conservation, animal welfare principles, and food safety [141].

Participants also suggested the IPDA explore setting up an agriculture data code of conduct, to advance farmers' interests in agricultural data and to support and build farmers' digital capability and confidence to participate in digital innovation. The IPDA is aimed at advancing the public goods approach to agricultural innovation. Participants at the high-level dialogue on IPDA did not directly use the language of benefit sharing or ABS. Nonetheless, they foreshadowed a new outlook and thinking on how smallholder farmers could benefit equitably from digital technology-driven innovations in agriculture. IPDA is potentially an important inclusive platform to assist with injecting more constructive thinking around ABS that reflects the current technological realities also reflected in GODAN's Code of Conduct toolkit discussed above.

3.3.6 Daring to rethink the ABS regime complex as we know it

In the normative work of the Plant Treaty over the last 20 years, the FAO's established e-agriculture programme, and the emergent IPDA initiative, we see a global approach to ethical and equitable considerations within the rubric of public goods and philosophy of agricultural innovation. As the broader landscape of digital technology converges with revolutions in the life sciences as epitomized by DSI and reinforced by data analytics, bioinformatics, and associated disciplines in bioengineering and omics, there is a clear valorization and reification of the power of data, big or small, as the determinant of value across disciplinary boundaries. That development has hardly shifted the undergirding logic of ABS and the inequity of the digital divide. Rather, the need for the equitable participation of smallholder famers and the less technologically endowed in the benefits of technological progress and for bridging the digital divide has become more compelling.

But what is in dire need of rethinking is an ABS orientation, given a new reality in which technology has upended conventional assumptions of "access". The imperative for "benefit sharing" leaves policymakers options to pursue, as a pragmatic matter. Closely related or complementary to this conceivable normative shift is the idea that a global network model of data integration as an iterative process for collaborative scientific and technology innovation is a challenge to the conventional fixation on data ownership in favour of data utilization. In this regard, effort now needs to be channelled into strategies to empower and develop the capacity of smallholder farmers to utilize digital resources.

The CBD, through its AHTEG, has opened the opportunity for ongoing elaboration of DSI and for exploring science and policy approaches to it. So far that effort has launched a new analytical quest for reconsidering ABS from the global and cross-sectoral perspectives. More than a decade and half ago, however, the Plant Treaty's MLS laid the foundation for that outlook on ABS with built-in compromises between global public goods and private sector interests in agricultural innovation. This was done through, among other things, the creative accommodation of optional patent claims for innovations associated with the 64 plant genetic resources listed in Annex 1 of the Treaty and the dedicated BSF as a pioneer global ABS template.

In rethinking a new ABS and data governance strategy suited to the DSI and digital-driven innovation, normative work through the Plant Treaty provides an anchor for the CBD and other regimes. Put differently, efforts at the CBD to explore DSI and ongoing concern about its ramifications for ABS may end up where the Plant Treaty has been, requiring a consolidated response that takes account of the disciplinary convergences in life sciences and the trend towards a global network model of integrated data resources. A major task in this potential pathway is how to reconcile the existing sector-specific architecture for sharing of genetic, genomic-resource, and other information. For the Plant Treaty, this is done through the GLIS pursuant to Article 17 [103]. For the CBD process, it is done through the Clearing House Mechanism courtesy of Article 18.3. And for the WHO PIP Framework, it happens through the WHO-coordinated network of laboratories under Article 5.1.1 [56].

There are four major international frameworks in which ABS norms have continued to evolve since 1992. Those are fragmented along the jurisdictional and sectoral mandates of the applicable instruments or organizations. The focus of the CBD and the Nagoya Protocol is on ABS in the context of terrestrial genetic resources acquired not earlier than 29 December 1993. The Plant Treaty's attention is on ABS relating to the 64 premium plant genetic resources and other accessions to that Treaty's associated CGIAR global gene banks. The UNCLOS' concern is with marine genetic resources found in areas beyond national jurisdiction, where ABS takes on a slightly different dynamic. For example, in such areas, there is no recognized entity serving as a provider with sovereign rights over such genetic resources. Considerations for FPIC do not arise in these areas as they do in the context in which Indigenous and local communities are involved. Through the PIP Framework, WHO engages ABS in the specific milieu of "H5N1 and other influenza viruses with human pandemic potential" [138], providing support for the development and sharing of vaccines and other associated public health benefits.

Norm development in all these regimes is premised on physical access to genetic resources. As is to be expected, the increasing obsolesce of that corporeal orientation has led each of the regimes to examine, at their respective levels of jurisdictional interests, the ramifications of the dematerialization of genetic resources through DSI or GSD (which is essentially a data-driven innovation) for ABS [56,64].

3.3.7 Ramifications for ABS: another look at the Plant Treaty's MLS

The focus on the ramifications of DSI for ABS is an idea that has led to a greater understanding of, if not compulsion towards, an inevitable shift in existing orientations to ABS.

First, as we observed earlier, DSI breaks disciplinary boundaries, unravelling the interconnectedness, interdependence, and complementarity of disciplinary convergences in the life sciences. As a result, the jurisdictionally fragmented template for ABS and genetic resources may need to yield to a more holistic approach. There is a need to recognize that DSI reflects the fluidity and exchange of knowledge, information, and data from agriculture to the fields of health, environment, climate change, and so much more.

The second awakening arising from the appraisal of the intersection of DSI with ABS is that DSI drives home the increasing role of a networked and decentralized model for universalization, creation, and utilization of big data resources, providing a boost to open science and open innovation.

Third, because of the second, the circumstances and logic for the pursuit of provenance of genetic resources and for insistence upon an "ownership" approach to data have a diminished power of persuasion in the emerging landscape for ABS. As we have indicated, benefit sharing and capacity-building for the providers of genetic resources – including smallholder farmers in food-insecure regions of the world – to utilize digital technology assets would possibly attract significant attention from creative law- and policymaking, as various stakeholders begin to rethink extant ABS architecture.

Laird and her coauthors observe that despite close to 30 years of significant investment in the implementation of ABS measures, "there is relatively little to show in the way of conservation, technology transfer, capacity-building, or other monetary and non-monetary benefits" [64]. Under all the fragmented regimes, including the CBD/Nagoya Protocol, the PIP, and even the Plant Treaty, ABS is mired in complicated and often non-productive bilateral agreements that take time to negotiate. In WHO's PIP Framework – where time is of the essence in responding to health crises through the sharing of critical pathogenic specimens and their sequences – contract-oriented ABS protocols are cited as real and a potential blockage to the requisite urgency.

Clearly, a combination of new technological realities – for example, those arising from DSI and the global dynamic for a networked data framework for open science and innovation – as well as the limitations of present ABS frameworks, feed the call for "rethinking the expansion of access and benefit sharing" [64]. Just like the inclusive approach adopted in the emergent IPDA, analysts argue that a broad cross-section of the scientific community needs to be drawn into new ABS policymaking. Laird and coauthors aptly note that "ABS has calcified over the years around a bilateral transaction for physical samples that is marginal to contemporary R&D, and the dissonance between ABS and scientific endeavour more broadly is only increasing. A new approach for ethically sharing the benefits of science and technology is sorely needed" [64].

Similarly, writing on "The future of information under the CBD, Nagoya Protocol, Plant Treaty, and PIP Framework", Lawson, Humphries, and Rourke call for the re-evaluation of the extant contract model of ABS [56]. They acknowledge the widely recognized realism that the value of genetic resources lies more in information or data – that is, the derivative model of genetic information represented in DSI or GSD. In their view, aside from a contract model, the cost or value of that information can be externalized under a separate arrangement from ABS, and it can take the form of "a charge, levy or tax" [56] or even a subscription fee. They argue that the "great advantage of externalizing the costs [of information] in a separate arrangement is to release the ABS transaction of the high costs of negotiating the value of information in each transaction and the central tenet of modern science that information is disclosed and shared" [56].

Of the existing ABS models pursuant to the CBD, Nagoya Protocol, and the PIP Framework, the Plant Treaty's MLS of ABS took a truly global approach to ABS before it was fashionable. The same is true of its inclination towards the informational content of plant genetic resources in the form of germplasm, as noted earlier. As a framework, the global tenor of the Plant Treaty is not diminished by its jurisdictional limitation to only the 64 crops and forages listed in Annex 1.

The Plant Treaty's worldwide MLS is forward thinking. Compared to even the CBD's later Nagoya Protocol, the Treaty is more attuned to the new reality in which the fragmented bilateral and contractual models of ABS are no longer as attractive as a practical matter. And perhaps most importantly even though there is little information to measure its result, the Treaty's dedicated BSF, with clear focus on the conservation objective of ABS and the public goods alignment of agricultural innovation, is one of the Plant Treaty's enduring normative legacies.

Beyond its origin in the Plant Treaty, the BSF as a concept, taps into the enormous flexibility for redesigning and rethinking ABS. As a springboard idea, it can morph and be adapted in responsive ways to extant convergences in technology and data-driven life sciences innovation. Already, the BSF parallels the call for levies, taxes, and subscription fees on genetic information as a de-materialized resource under the new technological reality. That reality reflects a strong shift towards networked global big data such as the INSDC for open science and innovation.

3.3.8 Decoupling access from benefit sharing: matters arising

A combination of the difficulties associated with the contractual model of negotiating access, the conundrum over the valuation of sequenced data, and the tracing of provenance has resulted in traction for the idea of "delinking access from benefit sharing for DSI, which will secure benefits while maintaining open science and generating funds from taxes, levies or tiered approaches that feed the multilateral fund" [64] (referencing Lawson, Humphries, and Rourke [56]).

The pragmatic suggestion that the interface of DSI and new technological revolutions in life sciences, including agriculture, inclines towards a reimagined ABS framework [56,60,64] (see also [68]) that downplays access while emphasizing benefit sharing warrants serious attention. Given the provocative nature of the idea, a lot more work is required to articulate the core strategy and priorities of that approach, taking into consideration all the emotions and rationale that have driven the "access" in ABS.

As a matter of first principle, conversations need to be inclusive of all stakeholders. Inspiration can be derived from the model of the IPDA examined earlier. It would require broad collaboration with all existing ABS implementing and instrumental frameworks and regime complexes, as well as with science and policy professionals across disciplinary divides in the life sciences. It would also involve the effective participation of and collaboration with the "provider cadre" of the ABS dynamic – notably, Indigenous and local communities, smallholder farmers, and traditional knowledge holders. Most importantly, the buy-in of developed and least developed governments of the Global South is a sine qua non. It would involve a determination to "reduce disparities, encourage accessibility, transparency and accountability" [60] and bridging ABS-targeted geopolitical asymmetry.

It is outside the scope of this study to engage in detailing the pathway for this monumental proposition for an inevitable normative shift. However, a few pointers and checkmarks are necessary. First, we have already highlighted the imperative to reconcile sector-specific global architectures for the sharing of genetic information under the four constituent strands of the ABS regime complex. Second, we need full realization that fixing the inequities of the digital divide and a public goods approach to innovation remains paramount.

3.3.8.1 Nuancing old assumptions in a new framework

In putting the stress on benefit sharing over access, the paradigm of users and providers of genetic resources and the corresponding North–South geopolitical binary remains. But the interface of ABS and DSI leaves that paradigm nuanced. For instance, the traffic of depositing and using digital sequences from the INSDC is perhaps better plotted based on increased scientific collaboration and partnerships among researchers around the world – in both developing and developed countries. Yet human resource, research, institutional, and infrastructural capacities remain uneven geopolitically. Naturally, biological resources in biodiverse regions of the world constitute greater targets for sequencing, even though the value of each sequence is in relation to others, including those sourced elsewhere. In a way, the nature and use of genetic sequence data prompts an analogy to the waning common heritage of humankind principle [60]. Similarly, DSI as a critical global informational resource reinforces our obligate interdependence, akin to the animating principles of the Plant Treaty's approach to humanity's interdependence on crop germplasms [142].

3.3.8.2 Relevance of physical and naturally occurring biological resources

It is hard to exaggerate the contribution of the digital sequencing of biological data and the wonders of synthetic biology for scientific discovery, innovation, and progress. Yet it is important to recognize that despite the capacity of synthetic biology and all the practical attributes of digital sequencing, these scientific and technological phenomena can only alleviate but not dispense with our reliance on physical and naturally occurring biological or genetic resources, including their wild relatives within a broader ecosystem framework. Consequently, in rethinking the ABS framework in the light of DSI, conservation remains an important objective to be kept alive. In the specific context of agriculture, the ecological diversity of the traditional landraces of smallholder farmers, especially women farmers, remains key to their contributions to conservation and the basis for farmers' rights recognized under Article 9 of the Plant Treaty. As well, those landraces are critical aspects of the food and nutritional security of the rural peoples in remote parts of the world in need of being supported as part of the conservation objective of ABS.

3.3.8.3 Holistic reconceptualization of benefit sharing

In reimagining the ABS framework, benefit sharing would take a more holistic and global outlook. The Plant Treaty's MLS of benefit sharing and Article 10 of the Nagoya Protocol on transboundary genetic resources provide inspiration for a global outlook on ABS that is now finding traction within DSI discourse. For example, the nature of DSI as a global asset with inherent public good and public benefit may have to be taken into account. As well, consideration may be given to the making and the creation of other elements of global public goods incidental to the use of DSI. A ready example is the use of the synthesized genome of SARS-CoV-2 uploaded onto the INSDC platform to develop diagnostic kits for COVID-19 detection. Overall, it would be important to conceptualize ABS and catalogue in detail the elements of benefit sharing suited for the open science module of DSI in a thoughtful, fair, and equitable manner.

3.3.8.4 Primacy of education, training, and inclusive capacity-building

Conceptions of capacity-building would need to shift from the lineal and one directional North–South mode [143] to an inclusive one, both in terms of geography and disciplinary inclusion. For example, the convergence of life science disciplines and the fluidity of data integration and exchange across those disciplines require scientists across geopolitical divides to acquire training and competence "to engage with complex policy processes" [64]. Education and training ought to be a huge component of this new normative shift in ABS. One of the principal aims is to support the capacity of those at the receiving end of the digital divide to optimally participate in and benefit from digital-driven innovation – in our case, especially in agriculture. It follows that education and training in digital capacity and digital literacy are critical for Indigenous and local community actors who double as traditional knowledge holders, biodiversity stewards, and smallholder farmers. As mentioned earlier, such training and education need to be systemic, entrenched, and sustainable. As well, they must be gender sensitive, given that the targets are frequently women who live in rural and food-insecure parts of the world. They also need to be conceived within the rubric of global cooperation with the United Nations and the SDGs.

3.3.8.5 Intellectual property and DSI: an uncharted territory for co-mingling of private and public interests

Another important agenda item for rethinking ABS for DSI relates to intellectual property. Meanwhile, the INSDC protocol recognizes the registration of patent-associated sequences. It does not prohibit the use of sequences sourced from the consortium database for intellectual property purposes. While the intellectual property issue in the DSI remains foggy and requires further exploration, the Plant Treaty's approach to the use of intellectual property and other intellectual assets associated with its stored germplasms is insightful. The Treaty's MLS requires payment of a fraction of royalties from intellectual property associated with R&D from the gene bank to be paid to the BSF. Again, despite the slow level of uptake of the BSF under the MLS, the Plant Treaty represents a source of insight regarding the accommodation of intellectual property and co-mingling of private sector interests with the overarching public goods objectives in a potential reconfiguration of ABS.

3.3.8.6 ABS as a big-ticket item for science policy and development justice

An idea worth exploring is that of a global levy, tax, subscription, charge – or howsoever called – in the form already foregrounded and mirrored by the BSF. The BSF is benchmarked to and within the jurisdictional limits of the Plant Treaty and FAO. A new global effort on ABS would be all-encompassing of interests – CBD/Nagoya, WHO/PIP, UNCLOS, etc. – within the regime complex of ABS. The new ABS would be a big-ticket global development investment and science and technology policy. Potentially, it could draw ABS into the justice of global governance. In the words of Aubry, "[p]roperly answering the challenges of dematerialization is a necessary condition to ensure that ABS instruments stay relevant in the state of actual science and fulfils their objectives" [60].

A key aspect of ABS would be to include capacity-building, investment in scientific collaboration, and research partnerships. The priority is to grow both human and institutional capacity for education and training at all levels – formal and informal and aimed at the equitable participation of all – in the benefits of the new digital and scientific revolution. As DSI has shown, the current regime complex on ABS has since collided with the open science and big data framework, marking the shift to a global, inclusive, and coordinated approach to ABS unavoidable. Given the enduring relevance of the Plant Treaty's normative groundwork on a global approach to ABS, FAO is strongly positioned through its influence and experience to engage in the anticipated ABS regime convergence and to facilitate dialogue across science, law, and ethical policy for rethinking ABS in alignment with the greater good.

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