A Digital Public Infrastructure Approach for the Agriculture Sector

Acknowledgements

This report was produced through a collaboration between Co-Develop, the Gates Foundation, the World Bank, Vital Wave, and OpenAgriNet. It was produced through a collaborative drafting process led by Vital Wave with substantial support from colleagues at the World Bank (Nidhi Parekh) and the Center for Open Societal Systems (Kirti Pandey). Financial support was provided to Vital Wave by Co-Develop and to the Center for Open Societal Systems by the Gates Foundation. The findings and conclusions contained within this document are those of the authors and do not necessarily reflect positions or policies of the Gates Foundation.

The authors would like to thank the digital agriculture and country experts who shared their time and insights during interviews in the development of this report. The authors would also like to thank the individuals who provided or contributed to structured written feedback on earlier drafts of the report, including (in alphabetical order by last name), Benjamin Addom, Yuvraj Ahuja, Alexander Amard, Jagadish Babu, Krishan Bheenick, Claudio Muniz Machado Cavalcanti, Stewart Collis, Katie Kennedy Freeman, Wairimu Gachera, Clement Gevaudan, Marianne Grosclaude, Sanjay Jain, Robert Karanja, Parvathy Krishnan Krishnakumar, Howard Lakougna, Stela Mocan, Parmesh Shah, Bekzod Shamsiev, Manu Srivastava, Jagadeesh Sunkad, Mitul Thapliyal, Tim Wood, Gisele Yasmin.

Executive Summary

As the world's population grows, the need to efficiently produce, store, and distribute agricultural products becomes increasingly urgent to improve food security and quality of life for over one billion people engaged in agricultural activities globally. Yet growth in agriculture productivity, particularly in Africa, has stagnated.

Digital tools have shown promise in addressing these challenges, helping improve yields and enhance inclusion in agricultural markets across low- and middle-income countries (LMICs). However, two persistent issues limit their potential. First, fragmented and siloed data systems limit the use of existing data. Efforts to digitalize agriculture have often been isolated investments, resulting in siloed data and duplicated systems that limit data use and the scalability of promising data systems. Second, market concentration threatens to keep smaller producers from benefiting from digital innovations. Large agribusinesses, with greater access to capital, are better positioned to adopt proprietary digital technologies, benefit from innovation, and access larger markets. This has, in many cases, led to the exclusion of small-scale producers who lack access to affordable and open digital solutions.

To address these systemic challenges faced by the sector and previous digitalization efforts, many countries are turning to digital public infrastructure (DPI) – an approach to building digital systems that are modular, interoperable, minimalist, reusable, and for public benefit. Foundational DPI encompasses sector-agnostic digital systems including digital identification and verification, fast payments, and data sharing systems.

The agriculture sector can leverage foundational DPI in multiple ways. For example, national identification systems can improve the targeting of agricultural subsidy and benefit programs. Digital payment systems can enable efficient transfer of input subsidies and access to credit. Data sharing systems can strengthen the linkages between buyers and sellers and deliver tailored, localized guidance to farmers by enabling linkages across various data sets such as global positioning system (GPS), weather, and agricultural input data. Leveraging foundational DPI for agriculture can form a virtuous cycle, increasing accountability and performance expectations, putting service agencies under objective scrutiny, and increasing service delivery.

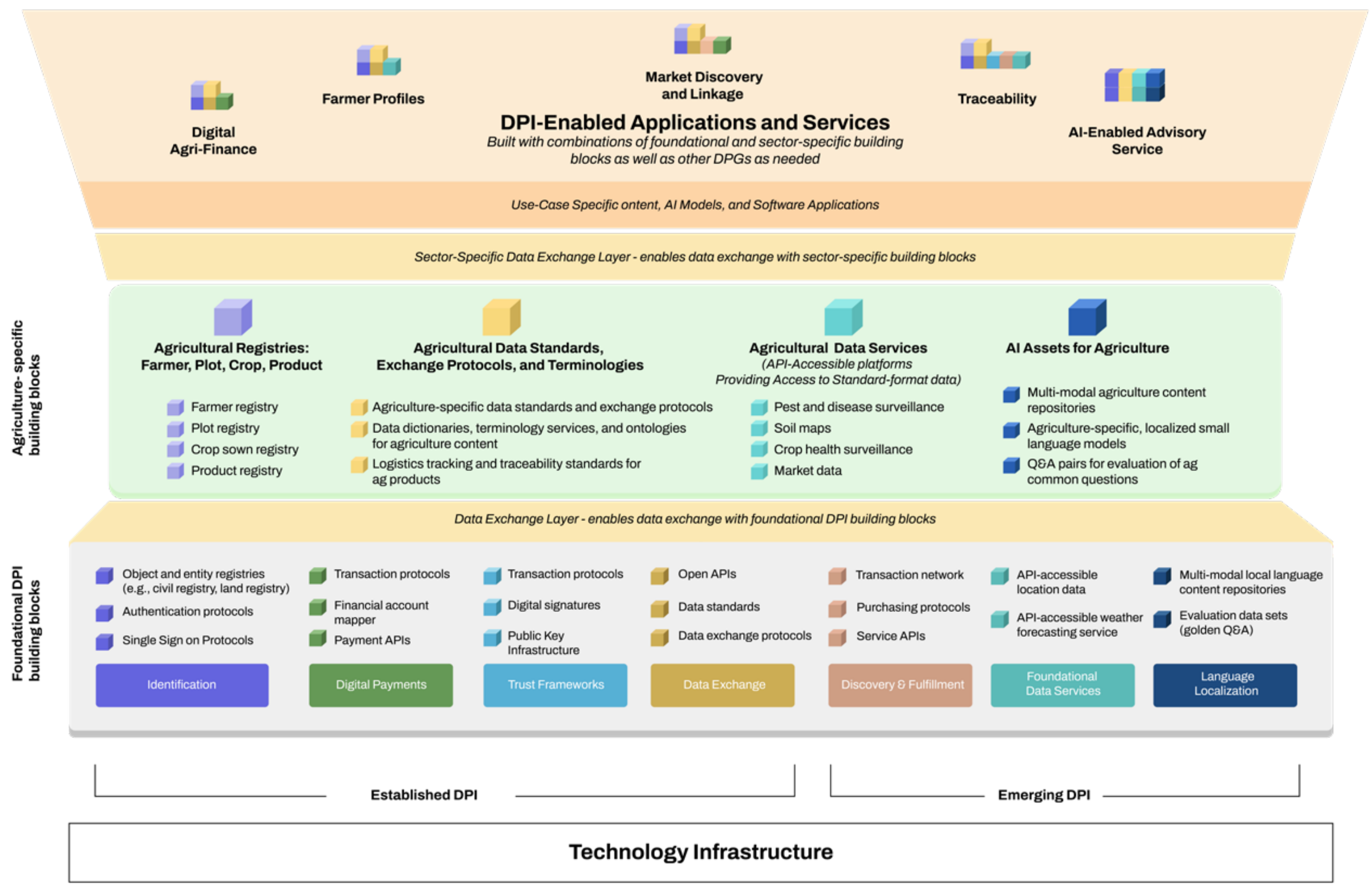
To enhance DPI's potential in agriculture, foundational DPI components (also referred to as sector-agnostic building blocks) can be complemented by sector-specific digital building blocks. Like foundational DPI, sector-specific building blocks should be designed using the DPI principles to be modular, interoperable, minimalist, reusable, and for public benefit. These sector-specific building blocks are not siloed implementations of foundational systems, but rather an additional layer of digital components needed to enhance the utilization of foundational DPI for the sector. For example, a farmer registry, which is a sector-specific building block, may utilize a foundational digital identification system to establish farmer identities (IDs), but the farmer registry will include additional data about a farmer (and the data standards to encode them), and likely be hosted in a distinct, interoperable system. This farmer registry acts as a sector-specific building block for the agriculture sector, just as digital civil registries act as sector-agnostic building blocks for foundational services. Sector-specific building blocks can be combined with other building blocks or foundational DPI to create desired use cases. See Figure ES-1 for further information.

For the agriculture sector, high-impact, sector-specific building blocks include:

- Relevant registries (for example, farmer, crop boundary, and crop sewn registries);
- Shared data standards and exchange protocols for agriculture data;
- Core data services, including maintenance of Application Programming Interface (API)-accessible, standard-format data sets for essential agricultural data like soil maps, pest surveillance, and market data;
- Agriculture-specific digital assets that will support the training and benchmarking of agriculture-specific language models to support widespread, multimodal AI-enabled services in local languages. These are agriculture-specific digital materials, like photos, texts, or recordings, which help train AI tools to give helpful farming advice in local languages using voice, text, or images.

When implemented using DPI principles, these building blocks can enable capabilities like agri-finance, farmer profiling, market discovery, product traceability, and AI-enabled advisory services.

Figure ES - 1 Foundational DPI and Sector-Specific Building Blocks Combine to Support an Ecosystem of Digital Agriculture Applications



Caption: *The Foundational DPI building blocks across the bottom row reflect those that support sector-agnostic capabilities. In addition to foundational DPI building blocks, achieving core capabilities for the agriculture sector requires additional, often analogous sector-specific building blocks (green row). These sector-specific building blocks can be combined in different ways with each other and with foundational building blocks to support a wide range of services and applications critical to meeting sectoral objectives.*

[i] a set of rules and protocols that allow different software applications to communicate with each other

Several countries are already leveraging foundational DPI building blocks as well as building and using agriculture building blocks. Where mature foundational DPI exists, for example, the digital identification system in India, it is being leveraged to create farmer IDs, support direct to farmer subsidy distribution, among other use cases. Simultaneously, countries like Angola, Ethiopia, Honduras, India, Kenya, and Lao PDR are developing farmer registries and other supporting registries, adopting standard data formats, or building API-accessible data services to enable tailored advisory.

From these examples across the landscape, several patterns are starting to emerge:

1. Articulating a clear rationale creates a foundation for investment. DPI can help address many, but not all, agriculture sector challenges. It is essential to begin with an understanding of the most pressing issues in the sector, identify priority solutions, and assess how DPI and agriculture building blocks investments can address them.
2. While the implementation of foundational DPI and agriculture building blocks is context-specific, there are many commonalities across countries. A set of template modules, which countries then customize by adapting architectures and sequencing investments based on their local needs and existing infrastructure, can serve as a starting point.
3. Whole-of-government coordination is essential to ensure data exchange across sectors, between land and agriculture ministries, for example.
4. Clear use cases and attention to user experience facilitate adoption. Digital tools are only meaningful if they address real user needs. Focusing on the goal of addressing an existing challenge and improving the user-experience will ensure better design and adoption, and savings will follow.
5. Successful implementation requires investment in enabling digital and analog ecosystems, including attention to market shaping and private sector engagement, financial sustainability of the digital products implemented as building blocks, improving the availability and quality of agriculture data, and continued efforts to strengthen data governance, privacy, and inclusion of digital systems.
6. Determining efficient ways to measure the use of DPI and its impacts will be important to evaluate long-term impacts and return on investment in DPI-enabled systems for agriculture.

While still in its early stages, the application of DPI in agriculture is gaining momentum. A growing community of organizations, including the Linux Foundation, OpenAgriNet, and the Agri Collaboratory, is working to develop digital public goods (DPGs), harmonize standards, and support countries in adoption and implementation. With this foundation, countries can begin to reshape their digital agriculture ecosystems – reducing fragmentation, unlocking innovation, and delivering inclusive services.

Ultimately, a DPI approach shows potential to increase efficiency, innovation, and productivity across the agricultural value chain to benefit small-scale producers, agribusinesses, and national-level stakeholders alike.

Table of contents

Acronyms

ADeX	The Agriculture Data Exchange
AGROVOC	Agricultural Research and Global Organization Vocabulary Organization Controlled
AI	Artificial Intelligence
API	Application Programming Interface
DPG	Digital Public Good
DPGA	The Digital Public Goods Alliance
DPI	Digital Public Infrastructure
EA	Enterprise Architecture
eKYC	Electronic Know Your Customer
FAO	Food and Agriculture Organization of the United Nations
FHIR	Fast Healthcare Interoperability Resource
G2P	Government-to-Person
HTTP	Hypertext Transfer Protocol
ICT	Information and Communication Technology
ID	Identity
INR	Indian Rupees
JSON	JavaScript Object Notation
KALRO	Kenya Agricultural and Livestock Research Organization
Lao PDR	Lao People's Democratic Republic
LLM	Large Language Models
LMIC	Low- and Middle-Income Countries
OAN	OpenAgriNet
ROI	Return on Investment
SSP	Small-Scale Producers
UPI	Unified Payments Interface

Introduction

Envision a world where farmers receive tailored advisory services directly on their phones in their native language. A world where agribusinesses can effortlessly connect with buyers and sellers through a digital platform. A world where small-scale producers (SSPs) access data-backed credit at affordable rates.

The digitization of the agriculture sector has taken steps towards this vision, yet many digital initiatives in agriculture have failed to scale and achieve widespread impact. Data is often siloed, systems are not interoperable, and small-scale producers are frequently excluded from digital services.

Recently, digital public infrastructure (DPI) has emerged as a potential remedy to fragmentation that facilitates scaling of impactful solutions. For governments and global donors, DPI is becoming a priority investment area to foster society-wide benefits, at scale. For private sector agricultural buyers and tech innovators, an ecosystem supported by DPI promises more competitive markets and innovations that are cheaper to make and faster to scale. For SSPs, it offers an on-ramp to critical services like input subsidies and loans, high-quality advisory, and improved access to markets. Yet for all its potential, there is ambiguity over what it means to leverage DPI for the agriculture sector and how to apply a DPI approach effectively within the sector. At the same time, there is an opportunity to cultivate interest in advancing a DPI approach across the sector and encourage action to realize its benefits.

This report aims to strengthen the collective understanding of how DPI, the foundational set of digital systems and the principles underlying it, can benefit the agriculture sector. It highlights the specific building blocks for agriculture, presents emerging country examples, and offers technical and policy insights for future implementers. It is aimed at funders and implementors working in digital development and agriculture. Given that the concept of DPI is new, this report explains the idea for a non-technical audience. However, to ensure depth and usefulness for implementors, it also discusses technical details regarding example architectures and specifications for digital agriculture systems.

Report Roadmap

Section 1 discusses the historical challenges of digitalization in agriculture and lays out the rationale for why the sector needs a new approach that focuses on combating data fragmentation. This section is relevant to those who want an introduction to digitalization in agriculture, such as digital experts with limited background in the agriculture sector.

Section 2 introduces the concept of DPI and outlines the key characteristics that are consistent across many organizations' definitions. This section is relevant to those looking for an introduction to DPI, such as agriculture experts with limited background on DPI.

Section 3 depicts how a DPI-enabled ecosystem creates value for different stakeholders in the agriculture sector by contrasting the experience with digital systems based on DPI characteristics to those of fragmented systems, which are common today. This section is relevant to those looking to explore the value-proposition of the DPI approach in the agriculture sector, such as policymakers in the ministry of finance or the head-of-state's office.

Section 4 extends the DPI approach to the agriculture sector. It offers a conceptualization of the complementary building blocks that are needed to fully utilize foundational DPI and create a DPI-enabled ecosystem. This section is relevant to those looking to understand how DPI consisting of a foundational set of systems as well as its principles can be applied to the agriculture sector. This includes all those who are looking to understand the possible capabilities and use-cases that this approach could support, such as policymakers in the ministry of agriculture, donors looking to invest in DPI for agriculture, or private sector companies exploring leveraging DPI.

Section 5 describes emerging examples of building blocks in the agriculture sector as well as country examples where foundational DPI is being leveraged for agriculture use-cases. This section is relevant to those looking for real examples of the DPI approach being leveraged in the agriculture sector, such as policymakers looking to learn from other country experiences.

Section 6 discusses technical implementation considerations for the building blocks outlined in Section 3. It examines three conceptual architectures for agriculture building blocks, each informed by existing examples. This section is relevant to those interested in the technical details of agriculture building blocks to leverage DPI in the agriculture sector, such as technical specialists in the government, private sector, or donor organizations.

Section 7 offers reflections on the current context in which many implementers may be working. It describes considerations and challenges relevant to adopting the DPI approach in many low- and middle-income countries (LMIC) landscapes. This section is relevant to those interested in understanding the common challenges faced by implementors, such as policymakers in ministries of agriculture or information and communication technology (ICT).

Section 8 goes beyond technical considerations to explore the multiple non-technical dimensions of a DPI-enabled ecosystem. It focuses on complementary strategies needed for DPI to succeed in its potential, including governance, market shaping, financial sustainability, monitoring, fostering inclusion, and protecting privacy. This section is relevant to those interested in exploring the non-technical enablers, such as regulators or high-level policymakers in ICT ministries or departments.

Section 9 synthesizes the insights throughout this document into an initial set of actions for interested stakeholders to put the DPI approach into action. This section is relevant to those looking to understand how to get started, such as donors or policymakers.

Section 10 presents a collection of current initiatives in the digital agriculture community focused on developing building blocks for the sector and strengthening the ecosystem for their implementation. This section is relevant to those interested in learning more about how to leverage the DPI approach in the agriculture sector.

SECTION 01

Imperative for Change in the Agriculture Sector

Key Messages:

1. Efficient, inclusive agri-food systems are vital for global development and sustainable development goals (SDGs) but face challenges such as inefficiencies, inequitable distribution systems, climate change, and decreasing farmer incomes.

2. Digital technologies can strengthen productivity, market access, and climate-smart practices, yet fragmented data systems limit their scalability and inclusivity.

3. Digital public infrastructure (DPI) offers a new approach to address fragmentation, foster open innovation, and facilitate more inclusive access to essential agricultural services.

Agriculture has a major role to play in the future of global development. Around the world, approximately one billion people,[1] including two-thirds of the world's poorest,[2] are engaged in or depend on agriculture for their livelihoods. The sector is key to achieving the sustainable development goals (SDGs), particularly those related to eliminating poverty and hunger, increasing responsible production and consumption, and tackling climate change (SDGs 1, 2, 12, and 13),[3] as well as protecting global biodiversity.

However, the global food system is complex, fragmented, and falling short of current and future needs. Despite significant increases in output,[4] the system struggles[5] with abundance and poor nutrition and hunger existing side by side. Globally, the agriculture sector is facing numerous challenges from food insecurity due to a growing population, the effects of climate change, declining farmer incomes, inequitable distribution of food produced, and stagnant or relatively low increases in productivity. By mid-2080, the global population is expected to reach 10.3 billion,[6] with demographic shifts putting additional pressure on agri-food systems, particularly in the Global South. Regular access to sufficient food remains a challenge; the Food and Agriculture Organization of the United Nations (FAO) estimated that in 2023, over 2.3 billion people[7] – nearly 29% of the world's population – experienced moderate to severe food insecurity. Declining farmer incomes and fragmented landholding have reduced productivity and financial viability for small-scale producers (SSPs). Climate change further affects livelihoods through impacts on yields, water access, and overall agricultural productivity.

Technological advancements present an opportunity for agricultural transformation and the emergence of digital agriculture as a field. Digital solutions have been introduced across the agriculture value chain to address the numerous challenges that farmers, value-chain actors such as off-takers and distributors, and governments face (Figure 1). For example, digital solutions can facilitate platforms for agricultural research and development. Inclusive digital finance solutions (such as digital lending and insurance products) have been shown to improve agricultural operating productivity. Digital payments systems facilitate access to and administration of subsidy schemes. Farmer-facing digital applications have provided climate-smart advisory services and open access to markets, improving competition and reducing waste. Continuing to identify and scale effective digital solutions will be an important part of achieving equitable and sustainable agri-food systems.

Figure - 1 Foundational DPI and Sector-Specific Building Blocks Combine to Support an Ecosystem of Digital Agriculture Applications

	Research & Development	Financial Access	Supply Chain Management	Enterprise Management & Efficiency	Market Linkage & Access	Advisory & Information
examples	Market research and analytics Discovery platforms Climate adaptability practices	Digital Fast Payments Tailored eligibility for input loans Insurance Person-to-person Lending	Value Chain Traceability Regulatory Compliance Verification Logistics & post harvest management	Farm management software Smart irrigation	Digital market places Digitally-enabled value chain integrators Climate marketplaces (for carbon, water, biodiversity)	Farmer information service Tailored online advice Digital advisory agents

Adapted from Beanstalk AgTech. (2023). State of the Digital Agriculture Sector: Harnessing the Potential of Digital for Impact Across Agricultural Value Chains in Low- and Middle-Income Countries.

However, as other sectors have experienced when introducing digital solutions and data systems, a solution alone is often insufficient to affect large-scale change. Solutions that are developed without shared standards and governance norms often operate in isolation and are unable to exchange data or be easily reused by others. For example, in many countries, data about who is farming, what crops are grown, the yield of crops grown, soil health, crop health, and agricultural market data are all held in separate data systems, accessible only by small groups of stakeholders, with duplicate systems within sectors and at different levels of the ecosystem. This makes it exceptionally difficult for governments to identify all those who are eligible for subsidy programs, for lenders to gauge the risk of input loans, for off-takers to anticipate what and how much product may be available, for producers to identify lucrative markets for the products, and for advisory information to be precisely tailored to the producer requesting guidance. Today, many actors participating in agri-value chains are operating with incomplete information that increases risk, lowers competition, and contributes to missed opportunities for better yield, higher incomes, and more sustainable agri-food systems. A recent landscape report of digital agriculture[8] identified a common set of challenges that limit the scale, sustainability, and commercial viability of digital agriculture solutions. Chief among these challenges are fragmented knowledge networks and data silos, which contribute to several other core challenges around exclusion, poor user engagement, and uncertain financial viability.

Further, the agriculture sector bears an additional challenge of the potential concentration of data and digital solutions among large private-sector players, as over time they have become the natural holders of more data and capital to invest in full stack solutions. Coupled with the data governance and capacity challenges governments face in effectively brokering access to such data, digitalization in the agriculture sector is particularly vulnerable to creating solutions that primarily serve those with ability to pay. This heightens the need for approaches that support low- or no-cost open technology solutions and inclusive pathways to participating in solutions development.

In response to these and similar challenges, the need for planned, system-level solutions that address fragmentation and encourage participation in ecosystem development have emerged in many sectors. In business, enterprise architecture (EA) has become a best practice for efficient digitalization. In health, the Open Health Information Exchange architecture has been promoted to combat fragmentation within the sector and encourage open innovation. And recently, within the agriculture sector, the concepts of national agricultural data infrastructure and digital public infrastructure for agriculture have emerged as a strategic way to invest in policies, governance, business models, and technology that will support data exchange for the agricultural sector. All of these frameworks move beyond investments in stand-alone digital solutions and instead focus on creating a robust, open set of systems and structures that are designed for interoperability.

For this paper, the specific focus on digital public infrastructure (DPI) stems from its potential to counter data fragmentation in the agriculture sector and to enable many digital solutions and solution-developers, working both within and across sectors, to leverage a strategic set of common functionalities.

SECTION 02

Digital Public Infrastructure – A New Approach

Key Messages:

1. Digital public infrastructure can refer to specific digital systems that comprise the foundation of a country's digital services as well as an overall approach of investing in digital systems and platforms that have the characteristics of foundational relevance, building block design, and governance for public benefit.

2. Common foundational DPI systems include digital identity (ID), data exchange, fast payments systems, and, sometimes, digital signatures, eConsent, and market discovery systems.

3. Leveraging foundational DPI and applying the characteristics of DPI to digital systems in the agriculture sector can reduce fragmentation and duplicative investments, encourage healthy competition, ease the scaling of effective solutions, and enhance equitable economic growth to meet the rising challenges.

What is DPI?

Investing in digital transformation through DPI offers a new approach for how countries build, govern, and maintain essential digital services.

DPI focuses not only on *what* to build, but on *how* to build it for scale and impact. Like the physical infrastructure of highways and railroads, DPI constitutes a set of shared digital systems that create a foundation for social and economic activity. Just as roads and railways can be used by everyone because they are built to standards that create consistency, DPI can enable broad participation in the digital ecosystems that enable key services for society. Similarly, just as physical infrastructure is constructed with oversight mechanisms to ensure trust in its safety, maintenance, and long-term utility, DPI includes governance structures that support safety, inclusion, and reliability.

The term “DPI” can refer to both the specific set of digital systems that, together, comprise the foundation for a country’s digital services as well as to an overall approach to investing in software systems and platforms that demonstrate a set of DPI characteristics described further below.

Familiar examples of DPI (used in reference to specific systems) include digital identity systems that enable identification of people or objects, or open data exchange protocols like hypertext transfer protocol (HTTP) that allow data to flow securely and with integrity across many discrete systems. Fast digital payment systems that securely facilitate financial transactions between two parties are another common example.

The term “building block” is used frequently in descriptions of DPI to describe discrete technology components that are part of the larger set of systems that comprise a country’s DPI. [ii, 9]

Emerging Definitions for Digital Public Infrastructure

While the overall vision for DPI is generally shared across key global actors, there are variations in specific organizational definitions of DPI. Some emphasize adherence with a defined set of technical principles, others have a stronger emphasis on governance, while others focus on characteristics common to DPI systems. See Appendix 1 for examples of definitions in the global community.

The World Bank’s recently released paper on DPI[10] seeks to synthesize and simplify existing definitions in a short, specific yet flexible definition: **“Digital public infrastructure (DPI) refers to systems that serve as foundational, digital building blocks for public benefit.”**

Nearly all organizations’ descriptions of DPI, including the World Bank’s, recognize digital identity, digital payments, and data exchange as examples of “core” DPI components, while acknowledging some flexibility in the emergence of others. For example, some DPI frameworks include components

[ii] GovStack offers this specific definition of building blocks: “software code, platforms, and applications that are interoperable, provide a basic digital service at scale, and can be reused for multiple use cases and contexts.” In general, building blocks are conceptualized as components of DPI, either on their own or when combined with other building blocks.

of digital consent and digital signatures, and sometimes, digital networks for the discoverability of services or products. Definitions also vary in breadth and reference to governance factors that might distinguish widely scaled, privately governed systems from those with more publicly accountable governance.

While precise definitions of DPI will continue to evolve, most reflect the combination of characteristics identified in the World Bank definition above: foundational relevance, modular and interoperable technology design, and governance for public benefit. A fourth aspect also frequently present in descriptions of DPI is its focus on ecosystem-level outcomes. Key details on these characteristics are described further below, with an explanation of what each dimension adds to the concept of DPI.

1. A focus on digital systems that have foundational, shared, society-wide relevance

Why it matters: The designation of DPI is generally reserved for digital functionalities or capabilities that are widely utilized across sectors and use cases. Focusing on functions with wide relevance reduces the potential for redundant and fragmented investments. Ideally, DPI is comprised of a strategic set of underlying digital functionalities that not only support many use cases but can also enhance the quality of necessary capabilities across sectors. This can happen, for example, by using providers that specialize in the common component to allow other entities to focus on their individual competencies.

2. Technology designed to be interoperable, modular, minimalist, and based on open standards, a "building block design"

Why it matters: The reference to building blocks in the World Bank definition, as well as others in the community, emphasizes that DPI is comprised of a set of discrete technological components that are designed to share information with other systems, be built upon by others, and if necessary, be exchanged in the future. This "building-block design" is also consistent with the design of digital public goods (which, in addition to the above characteristics, also share the quality of being open-source). The use of technology that is interoperable and based on open standards reduces the potential to introduce bottlenecks or dependencies on a bespoke software component. At the same time, minimalist, modular design facilitates combination and recombination between individual building blocks. This enables new services to utilize precisely what is needed and avoid redundancy and unnecessary complexity.

3. Implementation with governance mechanisms for public benefit, (e.g., inclusion, public accountability, and protection of basic rights and freedoms)

Why it matters: Governance of the systems that comprise DPI should embed principles that ensure their use in the service of social participation and benefit. Previous experience with digitalization has shown that digital technology is not neutral. Without attention to principles like inclusion, data protection, privacy, public oversight and accountability, and user choice and control, even well-meaning solutions can contribute to harms like exclusion from services,[11] unauthorized data use, and failure to produce intended benefits. Given the essential nature of the services DPI supports, ensuring their implementation is governed in accordance with these principles is critical to maintaining public trust.

4. Capacity to achieve ecosystem-level outcomes

Why it matters: Many definitions also describe DPI as producing outcomes at scale. This suggests that it is not sufficient for systems with building block design and societal relevance to merely exist; to truly function as DPI, they should be utilized by stakeholders within the ecosystem and contribute to innovation, service delivery, and broader participation in the ecosystem. This aspect of DPI is emergent and dependent on the broader environment in which it is implemented. However, investing in digital systems with cross-sectoral relevance, building block design, and adherence to governance principles can facilitate use at scale within country digital ecosystems.

SECTION 03

The Value Proposition of DPI-Enabled Systems in Agriculture

Key Messages:

1. Countries that have invested in DPI demonstrate how it can create value for individuals, governments, and private-sector actors engaging DPI-enabled ecosystems.

2. Within the agriculture sector, using DPI systems and the DPI approach offers potential to:

    - Enable SSPs to securely and digitally access critical services like input subsidies and digital extension services.

    - Reduce uncertainty for aggregators and wholesalers by strengthening data sharing and visibility across value chains.

    - Facilitate rapid innovation on top of foundational services by promoting use of interoperable, minimalist, modular technology components.

    - Create significant efficiencies for governments in the administration of benefit schemes.

DPI offers an approach to digitalization that enables efficient and inclusive evolution of an ecosystem of digital services over time. Leveraging foundational DPI and applying the characteristics of DPI to digital systems in the agriculture sector can reduce fragmentation and duplicative investments, encourage healthy competition, ease the scaling of effective solutions, and enhance equitable economic growth to meet the rising challenges. In contrast to an ecosystem of fragmented data systems, the DPI approach can create greater efficiency, innovation, and productivity by creating key functionalities as shared, interoperable public assets. DPI allows for foundational systems to be reused across programs, platforms, and service providers – reducing duplication, enhancing service consistency, and enabling faster innovation.

While DPI is not a panacea for all challenges in digitalization, it is a strategic investment to overcome the data fragmentation challenges so many countries experience. Many countries have already invested in DPI.[12] There is now an opportunity to leverage these foundational investments for agriculture. For instance, enabling data exchange across farmer, crop, and land registries can relieve uncertainty around financial viability and enhance investment. Strengthening data exchange to enable digital advisory on management practices and outcomes facilitates expanded reach of climate-smart agriculture practices. Improving availability of market access data to enable wide discoverability and ease participation makes the digital agriculture ecosystem more inclusive and competitive. To bridge the gap from the current state to the future state of global digital agriculture, the sector must pivot toward transformative approaches – like DPI – that address systemic challenges of fragmentation at scale.

Examples of the Value of DPI for Different Stakeholders

When implemented effectively, the DPI approach facilitates inclusive participation from both public and private sectors, enables solutions to scale beyond fixed-term development projects, and, given standards-based and interoperable design, supports rapid innovation by making it easy to build on top of common capabilities. Figure 2 illustrates how different stakeholders in the agriculture sector stand to benefit from the DPI approach compared to the limitations they face in fragmented digital environments.

Figure 2 Illustrative Value of Services or Functionalities Enabled by the DPI Approach for Agriculture Ecosystem Stakeholders

Small-Scale Producers (SSPs)

With fragmented systems	With DPI-enabled systems
Experience limited and sometimes interrupted access to services and innovations, dependent on the scope and scale of discrete projects.	Experience continuous access to farmer-facing services such as tailored advisory due to the reusable, interoperable building blocks approach.
Repeatedly provide personal data across multiple platforms to access loans, insurance, and subsidies. This takes time and raises the risk of potential misuse.	Use secure, consent-based data exchange from registries to other entities means SSPs rarely input personal details repeatedly to access relevant services for which they may be eligible.
Are dependent on market platforms with limited reach and low competition.	Access broader, more competitive markets enabled by interoperable platforms and open protocols.

Value Chain Actors (Input Lenders, Off-Takers)

With fragmented systems	With DPI-enabled systems
Face high uncertainty given the opacity of farmer history and yield patterns, forcing greater risk of investments and inefficiencies in production.	Have greater visibility into farmer history given wide use of consent-based and standardized data exchange, reducing risks of investment and expanding consumer base for loans and insurance products.
Struggle to comply with regulatory requirements on sourcing given fragmented and unstandardized data on product provenance.	Experience streamlined compliance procedures given widespread use of data standards for traceability and improved supply chain management decisions given visibility into product availability, quality, and processing needs.
Have limited visibility into available market, contributing to less competitive pricing.	Experience improved competition given enhanced exchange of market data, which increases the range of potential buyers.

Innovators

With fragmented systems	With DPI-enabled systems
Have a high burden of creating new solutions, repeating investments in collecting farmer details, curating data sources, and working to find partners to contribute to independent platforms for market transactions or advisory.	Engage in increased innovation given availability of shared, open building blocks that are interoperable and lower investment in common components.
Require more financing and limit provision of free or low-cost access to enable return on investment.	Are able to more quickly scale solutions with lower investment, given interoperability of core components.
Experience high competition as a result of the investment needed to collect high-quality data and build useful tools, which limits willingness to collaborate across the ecosystem.	Have confidence in continued ability to access shared resources, leading to greater collaboration and mutually beneficial solutions.

National-Level Actors (Public and Private Sector)

With fragmented systems	With DPI-enabled systems
Must make market and policy decisions in the absence of real-time population needs because relevant data remains siloed across institutional, national, sub-national, public, and private databases.	Have access to foundational data to make market, subsidy, and import decisions based on timely data.
Pay higher costs of implementing subsidy, loan, and agricultural services given reliance on bespoke solutions.	Pay lower costs or invest more in niche aspects of the product or service because relevant data about farmers, soil, weather, markets, and other critical aspects of agriculture are readily accessible via APIs and common data exchange protocols, reducing redundant investments in collecting and consolidating data.
Miss opportunities to improve farmer outcomes because some segments of the population are not identifiable or reachable, making them consistently excluded from programs and opportunities to improve yield.	Reach more SSPs, given the ease of implementing and identifying eligible recipients for support schemes. This increases participation in market platforms and advisory services, eventually improving sector productivity and food security.

India Case-Study

The Value and Cost of the DPI Approach for Agriculture

While robust estimates on the impacts and costs of the DPI approach for agriculture are limited given that this is an emerging area, the following case-study attempts to present the benefits of the DPI approach for agriculture along with some of the associated costs.

India's digital agriculture journey illustrates how foundational DPI – comprising identity (Aadhaar), payments (Unified Payments Interface or UPI), and data exchange (Data Empowerment and Protection Architecture or DEPA) – can be leveraged and layered with sector-specific building blocks to drive agricultural transformation. The rollout of Aadhaar in 2009 enabled large-scale eKYC processes, which in turn facilitated financial inclusion through the 2014 launch of the Pradhan Mantri Jan Dhan Yojana (PMJDY). Together with the adoption of Direct Benefit Transfers (DBT), the post-2016 surge in UPI usage, and innovations such as the Aadhaar-enabled payments systems (AePS) targeted at rural households, these developments helped create a robust digital foundation for financial inclusion and last-mile service delivery.

This foundational infrastructure has significantly enhanced the efficiency and targeting of agriculture schemes. For instance, Aadhaar-based verification helped remove 21 million ineligible beneficiaries [13] under Pradhan Mantri Kisan Samman Nidhi (PM-KISAN), a direct income support program for farmers, resulting in government savings of approximately US $2.65 billion[14] (₹22,106 crore). Similarly, the integration of Aadhaar-linked point-of-sale systems in fertilizer distribution enabled targeted subsidy delivery, reducing fertilizer sales by 15.8 million metric tons [15] and saving the government around US $2.2 billion [16] (₹18,700 crore).

These foundational layers laid the groundwork for agriculture-specific building blocks like AgriStack, launched in 2021 (See Section 4 for more detail on sector-specific building blocks.) AgriStack comprises federated registries of farmers, land parcels, and crop data, linked via Aadhaar, to power a growing ecosystem of services including input subsidies, digital credit scoring, personalized advisories, and insurance.

For example, in Bihar, the Bihar Krishi platform leverages AgriStack registries to deliver integrated services across 16 modules. It has reached[17] over 500,000 farmers, 25% of whom are women, connecting them to more than 50 government schemes and delivering over 15 million advisory messages. Similarly, to enable secure data sharing between actors, Tamil Nadu launched the Agriculture Data Exchange (ADex)—a DEPA-compliant API layer that allows farmers to consent to share data with input providers, fintechs, and agribusinesses.

The building blocks are also beginning to unlock innovation across states. For example, e-Samriddhi, a fertilizer e-voucher scheme, uses land and crop data to authenticate eligibility and prevent leakages. Krishi Mangal builds on the digital infrastructure to provide climate-smart advisory tools to farmer collectives. Similarly, MooPay, a digital payments platform developed for dairy cooperatives, uses Aadhaar-linked bank accounts and mobile-based workflows to facilitate real-time, transparent payments to dairy farmers to ensure timely and traceable income flows from milk sales.

However, these digital gains have required significant public investment and an approach to governance that supported use of the available building blocks. On foundational DPI, the Government of India mandated free Aadhaar-based authentication until December 2019 and mandates zero-cost for basic peer-to-peer and merchant UPI transactions till date.[18] Further, the government spent over US$130 million[19] (INR 1,148 crore) on marketing and incentive schemes to drive adoption of UPI. Similarly, India's Digital Agriculture Mission allocated US $340 million[20] (INR 2,817 crore) to establish core digital infrastructure and registries, with an additional US $720 million[21] (INR 6,000 crore) in special central assistance earmarked for states.

For countries undertaking investments in DPI or sector-specific building blocks, a robust context-specific estimation of the benefits and costs, and a return on investment analysis can help shape the investments. The report discusses further considerations for such analyses in Section 9. The World Bank, along with other partners, aims to undertake such an analysis to inform countries' investments in DPI for the agriculture sector.

SECTION 04

Leveraging DPI in the Agricultural Sector

Key Messages:

1. Leveraging a DPI approach in the agriculture sector includes using foundational DPI systems for key agriculture use cases as well as investing in complementary, sector-specific building blocks that are tailored to the nuances of agriculture data and support key use cases for the sector.

2. Key building blocks for the agriculture sector include

    - Registries of farmers, geo-referenced crop boundaries, crop sown, and other comprehensive lists of inputs and products utilized in the national context.

    - Data standards, data exchange protocols, and common vocabularies to enable interoperability of systems sharing agriculture-related data.

    - Data services for core agricultural domains like soil maps, pest surveillance, and hydrologic data.

    - Specific assets for AI solutions, including API-accessible multimodal dataset for training models, small language models trained on local language agricultural content, and Q&A pairs for model benchmarking.

3. Combining foundational DPI systems with sector-specific building blocks creates capabilities for farmer profiling, agri-finance, end-to-end traceability, tailored advisory and extension services, and more.

The remainder of this report extends the DPI approach to the agriculture sector and explores how the vision of DPI-enabled systems can be realized. For example, foundational digital identities (IDs) and digital payment systems can enhance access to critical services such as input subsidies, agricultural credit, crop insurance, and real-time advisory services – key tools for mitigating risks and improving productivity and income. Similarly, digital payment systems and data sharing capabilities can support online marketplaces, reduce transaction costs and expand market access. Figure 3 depicts the potential agriculture applications and objectives of foundational DPI systems. Further, foundational DPI elements offer opportunities for tailored configurations to suit the specific needs of the agriculture sector. For instance, digital ID systems could incorporate credentialing and authentication methods designed for rural and remote populations with lower connectivity.

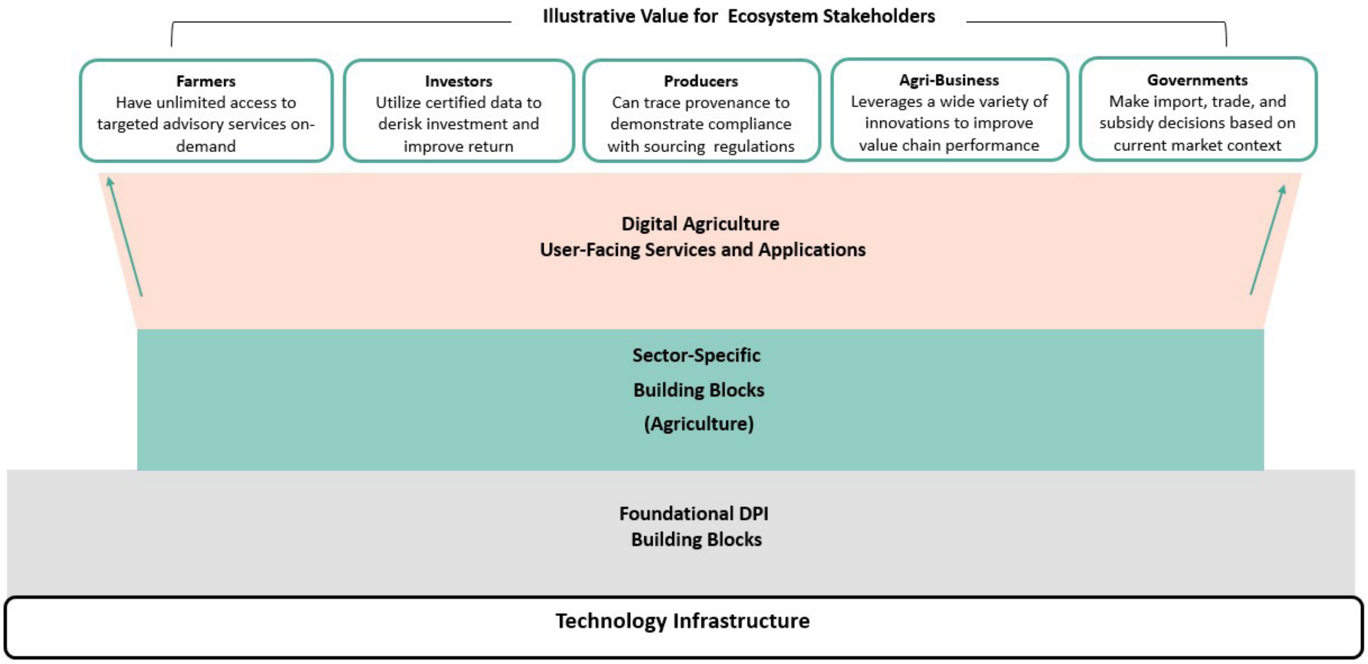
Figure 3 Potential Agriculture Applications and Objectives of Foundational DPI Systems

Foundational DPI System	Potential Agriculture Application	Objective
Digital Identity, electric Know Your Customer (eKYC), and e-Sign	Verify farmers, farmer producer organizations (FPOs), cooperatives for scheme access, subsidies, and traceability and for contracts	Enhances targeting, reduces fraud, builds farmer trust ecosystems
Digital Payments	Disburse subsidies, procurement payments, crop insurance, climate-linked payouts	Promotes financial inclusion and liquidity in agri-value chains
Data Sharing Infrastructure	Enable sharing of agronomic, climatic, pest, and market data through consent-based systems	Fuels precision farming, real-time advisory, and climate adaptation

While foundational DPI enables essential cross-sector functions like identity verification and payments, it does not easily manage sector-specific data or workflows such as crop types, soil conditions, or pest outbreaks. Without additional digital infrastructure tailored to the agriculture sector, it is difficult to overcome the historic fragmentation within the sector. Sector-specific building blocks help bridge this gap, enabling more precise, inclusive, and responsive agricultural services. Hence, this report focuses not only on how the sector uses foundational DPI, but on a complementary set of agriculture building blocks, like farmer registries or crop tracking databases, that work with foundational DPI to limit fragmentation and support a wide variety of user-facing services and applications[iii] for many use cases within the agriculture sector (Figure 4).

[iii] User-facing services and applications may be fully digital applications, or, alternatively, services that engage other actors. This is particularly important for farmers who remain unconnected to the internet and do not have smartphones to be able to benefit from services through extension agents or service centers. The digital divide and low literacy levels are still significant challenges, and this layer acts as a bridge to connect people to digital services. Such an approach has already been used through agents in the financial services industry.

Figure 4 **Sector-Specific Building Blocks Complement Foundational DPI to Enable a Wide Range of Sector-Relevant Services and Create Value Across the Ecosystem**



Defining Agriculture-Specific Building Blocks

- Agriculture-specific building blocks **are not siloed digital systems, but rather additional digital components purpose-built for agriculture** (e.g., sector-specific, interoperable systems, platforms, or sets of standards and protocols). For example, a farmer registry may utilize a sector-agnostic digital identification system but will also include specific types of data about a farmer (and the data standards to encode it) that will be different than those in sector-agnostic registries. This farmer registry acts as a building block for the digital agriculture sector just as civil registries act as sector-agnostic building blocks for broader social services.

- Sector-specific building blocks can be **combined with other sector-specific building blocks and/or foundational DPI** to create desired capabilities and use cases within and across sectors. These components should, as much as possible, adapt or extend the functions of foundational DPI, for example using a national identification (ID) to create farmer profiles, and add agriculture-relevant content, such as crop or plot-level data.

- Sector-specific building blocks should be **designed based on the DPI principles to be modular, re-usable, interoperable, minimalist, extensible, and governed for public benefit**. They must be built to enable developers to easily use, build on, and as necessary, substitute different systems as software evolves. This also facilitates the use of these sector-specific building blocks with other current or future sector-specific and sector-agnostic building blocks.

In most cases, the key building blocks for a sector should have at least one counterpart that is sector agnostic; however, given that country investments in DPI manifest at different paces, it is possible that sector-specific building blocks may be developed before foundational DPI systems exist.

Illustrative Examples of Agriculture-Specific Building Blocks

This section details the functionalities of sector-specific building blocks for agriculture and identifies candidate examples of specific building blocks that align with many, but not necessarily all, DPI characteristics.[iv] The sector-specific building blocks described below are an illustrative starting point, not a definitive list.

Registries

Registries are canonical lists of entities with associated data. They enable unique identification of entities, which might include people, objects, or locations. Foundational DPI, for example, includes a registry of persons with unique identification. For agriculture, key registries include farmer registries, plot registries, crop sown registries, and registries for inputs and products, amongst others.

Analogous sector-agnostic building blocks: civil registries and digital identification systems

Farmer registries – digital systems (e.g., databases) that organize information about farmers including personal details (ideally linked to those in a foundational ID system), farmers' current and prior crops, yield history, and associated assets. The particular indicators included in a farmer registry may vary across contexts.
Illustrative example: OpenSPP Farmer Registry

Crop sown registries – digital systems or databases that record specific crops planted and their location. Details included in the registry may include the farmer planting the crop, specific variety or type of crop, planting season, and other details that provide a window into the agricultural status and capacity of the region covered by the registry.
Illustrative example: AgriStack component: Crop Sown Registry

Agricultural product registries – a dynamic database of agricultural products that can be useful for marketing and sale of agricultural inputs including fertilizers, pesticides, seeds, equipment, and other products purchased throughout the agricultural value chain. *Illustrative example: registry software configured for products, e.g., Sunbird RC configured for products, or AgriStack's fertilizer registry.*

[iv] *For example, many products today may offer more than one functionality and thus may not be strictly minimalist. Whether specific instances of products function as a sector-specific building block also depends on local governance practices, which may not always align with the public benefit characteristic of DPI. The landscape of products available, and the maturity of those products will continue to evolve. Examples are included here for conceptual clarity, recognizing that not all products are perfect examples.*

Sector-Specific Data Exchange Standards, Protocols, and Terminologies

Key building blocks related to data exchange[v] in agriculture include data exchange protocols, data standards, and terminologies.

Exchange protocols and data standards are the first two important building blocks for data exchange within and between sectoral systems. A protocol is used to define how data is exchanged, while a standard describes the format of the data being exchanged. For example, HTTP is both a protocol and a standard. The HTTP protocol defines how clients and servers communicate with each other over the internet. It is based on a formal set of standards maintained by the Internet Engineering Task Force. In the health sector, Health Level 7 Fast Healthcare Interoperability Resource (HL7 FHIR) is becoming the de facto data exchange standard to define how to structure health data so that different systems can interpret messages. While FHIR uses the HTTP protocol, the FHIR standard defines the application program interface (API) that is used for data exchange. Foundational digital-identity DPI relies on several protocols and standards, which can include OpenID Connect (OIDC) as well as the World Wide Web Consortium's (W3C) Decentralized Identifiers (DID) and Verifiable Credentials (VC).
The agriculture sector similarly requires shared exchange protocols and data standards. Data exchange protocols for agriculture are nascent, though FarmStack is an example of an open-source protocol specifically tailored for the sector. AgriJSON (JavaScript Object Notation) is an emerging data standard that provides a structure for specific, common types of agriculture data that are not catered to by more generic standards.

Terminologies (also called taxonomies, ontologies, or controlled vocabularies) are a third type of building block which support semantic data exchange. Systems can only interoperate when they share understanding of the meaning of the data, and standardized terminologies are utilized to enable this. Terminologies are complex, and in the absence of a defined and accepted global list, often differ widely across organizations, regions, and countries.

In the agriculture sector, Agricultural Research and Global Organization Vocabulary Organization Controlled (AGROVOC) is one example of a terminology list. AGROVOC is a machine-readable Linked Open Dataset (LOD) that describes agricultural data, enabling a common understanding of terms and the exchange of agricultural data. The Food and Agriculture Organization of the United Nations (FAO) coordinated development and maintenance of AGROVOC, which consists of over 40 thousand concepts and one million terms in 42 languages.

Analogous sector-agnostic DPI: Representational State Transfer application programming interface (REST APIs), HTTP for transfer of text, video, image data; Beckn protocol *for transactions*

Data exchange protocols for agriculture data – sets of rules for exchanging agricultural data between systems in standard formats.
Illustrative example: FarmStack

[v] *The term "data exchange" here refers to technical structures that security transfer data between systems ensuring that the accuracy and meaning of data remains intact. It enables many-to-many, bidirectional transfer of data.*

Data standards for agriculture data – data models that provide a standard, structured format for agricultural data points that are commonly collected and exchanged across the sector. These ensure integrity in the representation of data as it is exchanged through a data exchange protocol.
Illustrative example: AgriJSON. agroXML

Terminologies for agriculture data – standard list of terms and definitions for key concepts commonly used in the agriculture sector.
Illustrative example: FAO's AGROVOC

Sector-Specific Data Exchange Standards, Protocols, and Terminologies

Core data services for agriculture are analogous to national weather data services or a geographic information system (GIS). For the agriculture sector, adopting the building-block design for a core set of data services granting access and transformation capabilities to data such as soil maps, market pricing data, and pest surveillance could enable many data-driven solutions for the sector, from advisory to post-harvest planning. These data services provide access to data that is distinct from the personal user data of specific farmers that might be captured in foundational registries. Rather, they include a core set of non-personal related data that can inform planting and harvest forecasts, diagnostics, and other advisory services. Developing core data services for the sector as building blocks would entail applying standard data formats as described above and a mechanism to expose, request, and share data with other stakeholders in the ecosystem (such as through an API). This requires governance to ensure the data are timely, reliable, and include appropriate metadata for informed use.

Analogous sector-agnostic DPI: GIS data services, weather forecasting services

For agriculture, illustrative data services might provide access and data processing capabilities to:

- **Soil data** (e.g., nutrient maps and services)
- **Market data** (e.g., pricing data)
- **Crop management data** (e.g., data sets documenting climate-adaptation practices)
- **Pest and disease data** (e.g., surveillance data)
- **Crop health** (e.g., via satellite or remote sensing)

Illustrative candidates for agriculture sector examples: Kenya Agricultural and Livestock Research Organization (KALRO) Data Sharing Platform, ADex

AI Assets for Agriculture

Numerous use cases are emerging for artificial intelligence (AI) and agriculture, including AI-enabled chat advisory, crop production predictions using remote sensing and earth observation, and AI-enabled varietal trait identification. To support these kinds of applications using a DPI approach, countries can develop interoperable, modular assets for training domain-specific AI models and enabling local language chat services to reach small-scale producers.

While few examples of these assets currently meet standards of DPGs or DPI building blocks, these could include:

- **Repositories of agriculture-relevant content for training AI models:** This refers to annotated repositories of multi-modal training content that are i) API-accessible, ii) relevant to the local context, iii) curated and updated under a governance model that includes conformance to agreed-upon data standards and annotation formats, iv) processed so as to contribute anonymized, appropriate content, and vi) compliant with applicable license terms (for example, a corpora of annotated images on pests and disease to enable development of AI-advisory solutions and services or labeled phenotypic data for trait identification).

- **Small Language Models for Agriculture:** Capturing the nuance and specific vocabulary used in communicating agriculture practices will likely require small language models trained on sector-specific content. Given that these linguistic nuances change rather slowly, investing in developing and maintaining one such model that performs well and meets governance characteristics of DPI could become a shared resource. Many users could then further fine-tune and adapt the small language model (SLM) for use cases involving digital communication to farmers in local languages. An illustrative building block could be an open SLM evaluated by a trusted entity and managed in a way that maintains an agreed-upon level of performance.

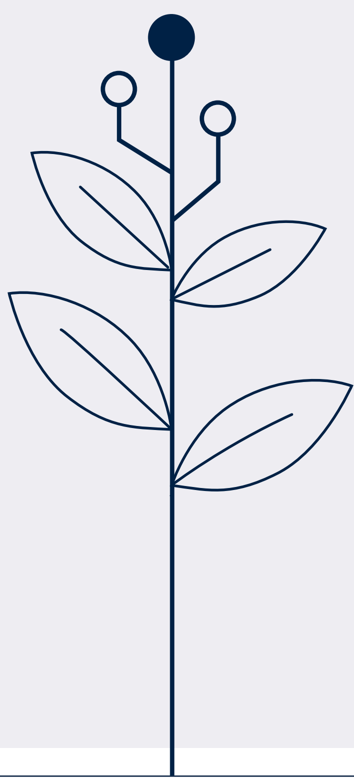
- **Q&A Pairs:** Like question and answer (Q&A) pairs for general large language models (LLMs), a curated set of Q&A for agriculture advisory could also eventually be a shared data asset that would create a baseline for performance evaluation of either general LLMs or SLMs that will be utilized for advisory tools. It would need to be a curated data set, informed by a trusted multi-stakeholder group of sector experts and innovators, developed in accordance with open data standards and formats, and API accessible.

- *Analogous sector-agnostic DPI: multi-modal content for language localization,[vi] e.g., content contributed through the Universal Language Contribution API (ULCA) used for India's Bashini.*

AI-related assets that lend themselves to building block design and use include:

- API-accessible repositories of domain-knowledge content, such as annotated photos for visual diagnostics and advisory, recordings or documentation from advisory interactions.
- Small language models in low-resource languages trained on agriculture-specific language. Because there are many local variations in crop names, how agricultural products are measured, and other domain-specific vocabulary, these small language models may prove an efficient, reusable unit for many agriculture advisory innovations.
- Q&A pairs for evaluation of agriculture advisory-focused models. While these kinds of assets are only just emerging, many may become DPGs in the future, and countries may adopt these kinds of assets as additional components of DPI.

AI and Agriculture



The intersection between AI and agriculture is further explored in a forthcoming World Bank report: Harnessing Artificial Intelligence for Agricultural Transformation. This report explores the many applications of AI in agriculture and how DPI creates a foundation for them. Specifically, the report highlights how personalization of services in agriculture will not be possible without rich data on farmers and the land they are farming captured in farmer IDs, verifiable credentials, and land registries. It highlights the role of core data services – structured, verified, accessible data on soil health, crop history, and market trends – in contextualizing data for the sector. It also highlights consent-based data sharing (to enable farmers to choose to share personal details that facilitate lending and contracting) as well as the role of open networks and interoperability standards to enable agricultural services to reach scale. These intersections reinforce the importance of both foundational DPI building blocks (including identification systems, land registries, open network protocols, consent mechanisms, and digital payments systems) as well as agriculture-specific building blocks (like farmer registries to create farmer IDs, and core data services for agriculture). The report further highlights the investment priorities in AI needed to support the use cases it explores, which include priorities around corpus development (including multi-modal data repositories of agriculture data, standardized data formats for agriculture, and low-resource language corpora to support translation to local languages), as well as agriculture-specific foundation models, which align with the emerging building blocks for AI described here.

[vi] *Most existing AI assets today are not necessarily built with a DPI approach. The content on which they are trained are not always accessible via API or open platform, and typically not subject to a governance model consistent with DPI. India's Bashini is one example of a language localization model that aligns more closely with the DPI approach and may become foundational as more social and sectoral services rely on digital language translation to local languages.*

What Capabilities Can Agriculture-Specific Building Blocks Help Create?

As previously discussed, a key characteristic of building blocks is relevance to a wide variety of use cases. The sector-specific building blocks identified above represent functionalities that have widespread utility for agriculture and have been vulnerable to siloed development in the past. This section highlights several key challenges for the sector and demonstrates how the sector-specific building blocks described above can be combined with foundational DPI building blocks to advance the following core capabilities[vii] for the agriculture sector.

- **Farmer Profiles:** refers to the ability to link multiple data points about farmers, including, potentially, contract histories.
- **Agri-Finance:** refers to multiple financial activities that support digital payment, lending, and repayment activities that occur across a value chain.
- **Agricultural Market Discovery and Linkage:** refers to using digital marketplaces to connect sellers of agricultural products to buyers.
- **Product Traceability:** refers to maintaining visibility into product provenance and tracking throughout the value chain.
- **AI-enabled Advisory Services:** refers to data-driven advisory services tailored to farmers based on specific considerations for their climate, soil, geography, and crop management capacity through a range of channels – extension agents, on-demand short message service (SMS), interactive voice response (IVR), or AI-enabled chat services.

Farmer Profiles

A major constraint to effective service delivery and business transactions in agriculture is the lack of an overview of relevant data related to individual farmers and their characteristics, such as of land farmed, crops farmed, yield history, subsidy receipt and/or eligibility, and contract history.[viii] By linking multiple disparate data points about farmers, farmer profiles can help facilitate personalized services. Comprehensive farmer profiles – underpinned by appropriate consent and data governance – can also strengthen business transactions across the agriculture value chain by reducing uncertainty. Farmer profiles are critical to many of the other capabilities subsequently described in this document. Additionally, farmer profiles are often a capability in themselves and are viewed as such by governments and private sector actors.

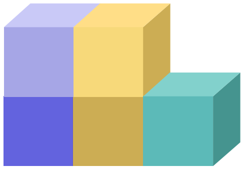
When combined with other capabilities, farmer profiles can enable:

- **Efficient benefit delivery:** farmer profiles enable more precise targeting of subsidy and scheme benefits to ensure those eligible receive benefits and reduce misappropriation.
- **Improved yields:** farmer profiles create a foundation for tailoring advisory services to specific climate, soil, and management contexts for better yields.
- **More trustworthy markets:** farmer profiles can be leveraged in credit decisions to lower risk of default, resulting in better returns and greater engagement with informal markets.

[vii] The term "capability" here describes a persistent capacity that results from using DPI building blocks in a given context. It emerges from the use of DPI and sector-specific building blocks at scale.

[viii] Visibility into verified contract histories of farmers, aggregators, and processors would enhance contract integrity, improve credit opportunities for farmers, improve trust across the value chain, and enable more efficient use of processor capabilities.

Relevant Building Blocks



- **Agriculture building blocks:** *farmer IDs, crop IDs, and plot boundaries (in associated registries) to link farmer and plot details, agricultural contract IDs and transaction records, agriculture data standards, exchange protocols, and common vocabularies to share data.*

- **Sector-agnostic building blocks:** *national identity systems and verifiable credentials to link contract history to individual entities, land registries to provide property details, APIs and related sector-agnostic data exchange protocols, consent protocols to enable authorized linkage of data, electronic signatures for secure execution of data-sharing agreements.*

Digital Agri-Finance and Subsidy Provision

Limited access to formal finance, including credit, remains a key constraint in agriculture. Digital agri-finance encompasses a range of digital financial services that support digital payment, lending, and repayment activities that occur across a value chain, from distribution of subsidies to loan eligibility assessment to payments for agricultural products.

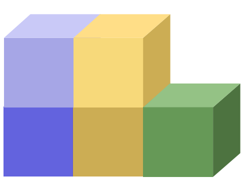
For SSPs, digital payments and linked financial services can:

- **Enhanced benefit delivery**: improve targeting, reduce time and effort costs to access government subsidies, and lower leakages and administrative costs to governments.

- **Affordable credit:** give SSPs access to data-based credit at reasonable rates to advance inclusion and empowerment, in particular for women and other vulnerable communities.

- **Safe, secure transactions:** facilitate secure and inclusive issuance of agricultural input loans, insurance and risk mitigation products, savings solutions, market transactions, and financial analytics. This could mark a significant shift away from SSPs' reliance on informal networks, savings, and moneylenders charging exorbitant rates.

Relevant Building Blocks



- **Agriculture building blocks:** *farmer and related registries to inform eligibility for subsidies and other schemes, agriculture data standards, exchange protocols, and common vocabularies to share data across registries*

- **Sector-agnostic building blocks:** *ast payments systems to facilitate execution of payment transactions, digital identity including electric Know Your Customer (eKYC) and authentication capabilities*

Evidence Spotlight

DPI in agriculture, including verifiable credentials and fast payments, can promote inclusivity, especially for SSPs who often lack access to essential financial and informational services. By integrating marginalized rural populations into formal economic systems, DPI enables them to access credit, digital payments, and secure insurance and other services. Research in other sectors has shown that the introduction of identity authentication into lending processes has improved credit markets, for example, by improving repayment rates for farmers in Malawi[22] and reduced leakage[23] in provision of government subsidy schemes. Similarly, research has shown that utilizing digital payment systems for input subsidies, e-vouchers, and other payments can reduce waiting time,[24] reduce delays[25] in cash transfers, improve women's control over cash[26], and improve household dietary diversity[27]. The combination of foundational payments and sector-specific building blocks can support use cases like subsidy payments, digitally-enabled input loan services, crop insurance, and agricultural market transactions.

Agricultural Market Discovery and Linkage

Limited access to markets is a critical barrier for many SSPs, who do not have the information to negotiate strong prices nor the ability to move or store products to accommodate more favorable conditions. Agricultural market discovery services digitally connect producers and buyers through open, accessible platforms. This enables sellers to see a wide range of potential buyers, creates visibility into market demand and price trends, and facilitates more competitive marketplaces to **increase farmer incomes, reduce waste, and increase market efficiency**.
Market discovery platforms offer:

- **Expanded access to markets:** Farmers can directly reach more buyers, bypassing intermediaries that often capture a large share of value.

- **Lower transaction costs:** Digital payments and interoperable data systems streamline logistics and settlement.

- **Innovation and competition:** Open, shared building blocks foster innovation, improving service quality and efficiency and the development of new digital markets.

- **Improved income and reduced waste:** Better price visibility and demand forecasting can reduce spoilage and empower producers to make informed decisions.

- **Foundation for other use cases:** Market discovery can also enable use cases such as marketplace applications, optimized matching services between buyers and sellers, and integrated advisory and marketplace platforms that direct farmers to optimal inputs based on local conditions.

Relevant Building Blocks

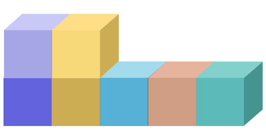
- **Agriculture building blocks:** *relevant farmer, product and crop registries, agricultural market data, agriculture data standards, exchange protocols, and common vocabularies to share data; (real-time) market data service.*
- **Sector-agnostic building blocks:** *relevant identifiers, buyer/seller matching protocols to connect farmers with buyers; consent management, digital payments to facilitate market transaction; data exchange protocols for financial transactions and sector-agnostic data.*

Product Traceability

Traceability addresses barriers related to the ability to prove product origin, quality, and production method (e.g. sustainable or organic certification). Traceability enables agricultural products and inputs to be tracked across the entire value chain, from production to consumption. Providing traceability can:

- **Improve post-harvest management:** visibility into the origin, movement, and selling of goods can lead to more efficient logistics, for example, tracking crop health, yield, and anticipated harvest date, and can help off-takers anticipate volume and more efficiently manage products.
- **Enhance sustainability:** verification and monitoring of certifications related to organic, fair-trade, and sustainably produced goods promote sustainable agri-food systems and give farmers visibility into the quality of their inputs.
- **Improve food safety:** ability to trace products aids compliance with safety standards and facilitates rapid recall in the case of contamination.

Relevant Building Blocks



- **Agriculture building blocks:** *crop registries and farmer registries to provide farmer and crop details; agriculture data standards, exchange protocols, and common vocabularies to share data on crops and farmers; agriculture and food-specific traceability standards.*
- **Sector-agnostic building blocks:** *Data exchange, sector-agnostic traceability standards (GS1 barcodes and electronic product code information services [EPCIS] messaging standard), digital signatures, eKYC, verifiable credentials; GIS data*

AI- Enabled, Tailored Advisory Services

AI-enabled advisory services can significantly enhance agricultural productivity by offering personalized, data-driven recommendations that reflect a farmer's specific conditions, such as climate, soil health, geography, and crop management practices. These services leverage comprehensive farmer profile data to deliver actionable insights on optimal inputs, irrigation scheduling, pest management, and harvesting strategies. Insights are typically generated by combining analytics with both foundational digital systems (such as weather and payment infrastructure) and agriculture-specific datasets (such as crop health and market demand). For example, AI-enabled systems can analyze real-time environmental and agronomic data to send alerts on imminent pest outbreaks or recommend the most suitable planting dates based on local weather forecasts.

For SSPs, digital-enabled, tailored advisory can offer:

- **Better input and harvest practices:** context-specific guidance – potentially powered by AI – on input selection, crop care, and harvest decisions.

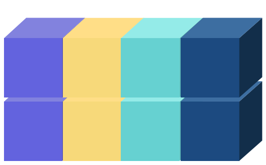
- **Expanded reach of advisory services:** availability of information through a range of digital channels, including extension agents using digital tools, SMS and IVR services for areas with limited connectivity or low literacy, and AI-powered applications that provide real-time, interactive support in local languages, enabling advisory to reach populations that may otherwise be excluded.

For off-takers and agribusinesses, digital advisory offers:

- **Enhanced post-harvest management:** forecasts on harvest timing, product quality, and post-harvest handling requirements can minimize loss and optimize distribution.

By aligning recommendations with localized data and individual farm profiles, tailored advisory services help reduce input waste, prevent crop losses, and boost productivity. They also support the adoption of climate-smart practices and improve access to timely information on weather, markets, and government support, strengthening both **farm-level outcomes** and **sector-wide resilience**.

Relevant Building Blocks

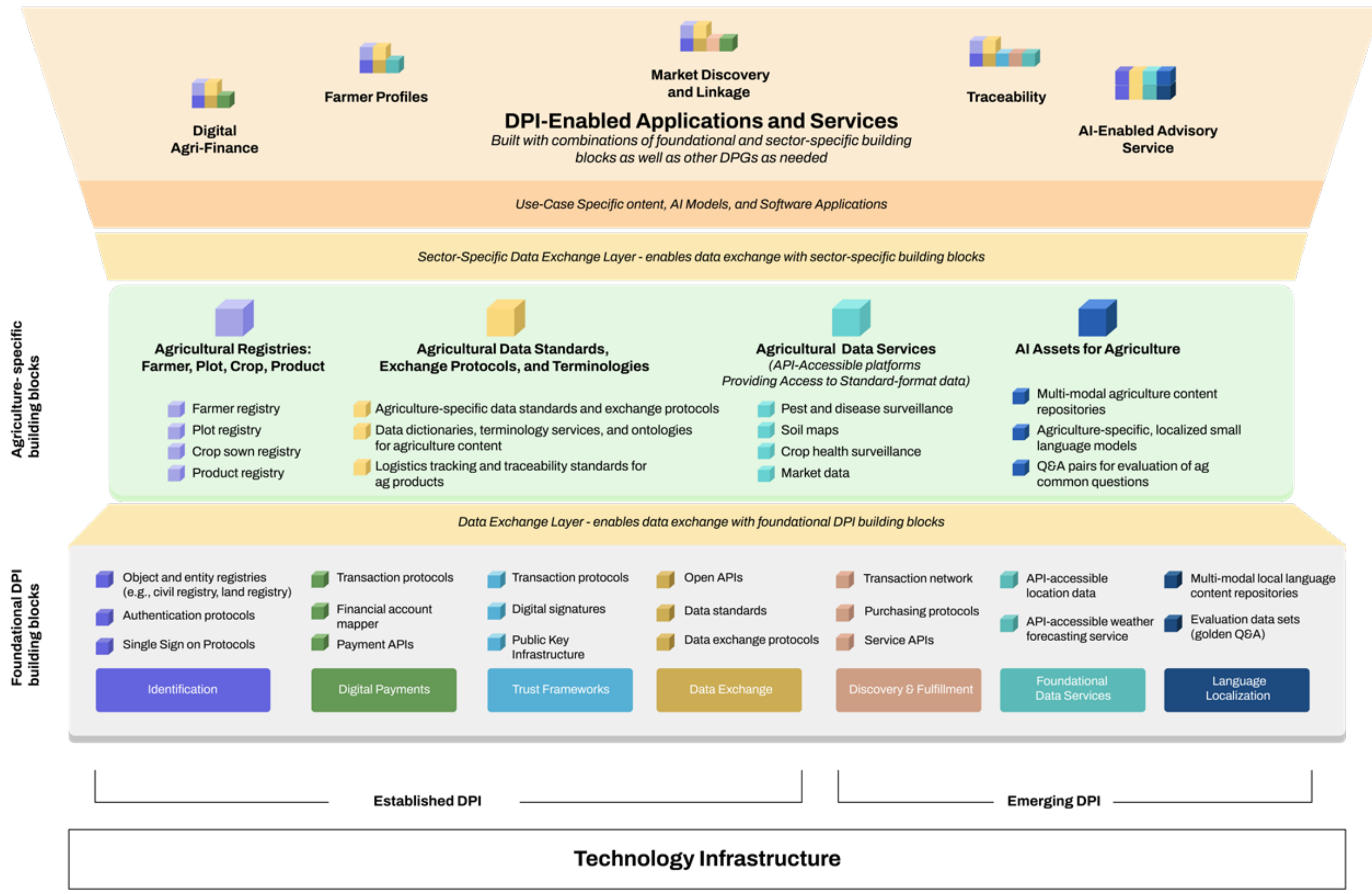


- **Agriculture building blocks:** *Farmer profile data to provide farmer or plot-specific details that inform advisory; agriculture-specific data standards; standard format and domain-specific content repositories for fine-tuning advisory models; small language models trained on local agriculture vocabulary; evaluation benchmarks for ag-specific advisory models.*

- **Sector-agnostic building blocks:** *Open, API-accessible data services for weather and climate forecasting; consent functionalities for access; multi-model content repository for training language models to support local languages.*

To show how these building blocks feature in a country's DPI ecosystem, Figure 5 adapts existing depictions of foundational DPI categories and building blocks from the Center for Digital Public Infrastructure to show how sector-specific building blocks can complement the use of sector-agnostic, foundational building blocks.[ix] Consistent with the description of foundational building blocks above, sector-specific building blocks are envisioned as functionalities that are modular, interoperable, and implemented with a governance model designed for public benefit. They can utilize foundational DPI and be utilized by a wide range of other digital public goods as well as private sector services and applications for digital agriculture. When these services are delivered at scale with this building block approach, country-level digital agriculture ecosystem will be able to achieve the desired capabilities reliably and at scale.

Figure 5 Foundational DPI and Sector-Specific Building Blocks Combine to Support an Ecosystem of Digital Agriculture Applications Services



***Caption:** The foundational DPI building blocks across the bottom row reflect those that support sector-agnostic capabilities. In addition to foundational DPI building blocks, achieving core capabilities for the agriculture sector requires additional, often analogous sector-specific building blocks (green row). These sector-specific building blocks can be combined in different ways with each other and with foundational building blocks to support a wide range of services and applications critical to meeting sectoral objectives.*

*Adapted from the **Center for Digital Public Infrastructure**. (October 2024). DPI Overview.*

[ix] Note, some versions of DPI consider trust frameworks and market discovery as part of data exchange, and, therefore, have only the three "core" DPI capabilities of identification, data exchange, and payments. The larger set is shown here for the sake of providing more specificity in the range of building blocks included in foundational DPI that may support sector-specific capabilities. Further, data standards, exchange protocols, and terminologies are shown as building blocks for data exchange. These are also represented as a horizontal layer given that these functionalities support data exchange with other foundational and sector-specific building blocks, as well as with the applications that utilize them.

SECTION 05

Country Case Studies

Key Messages:

1. Multiple countries are already working to implement a DPI approach in the agriculture sector.

2. As a country with longstanding foundational DPI, India has multiple instances of developing agriculture-specific building blocks that utilize foundational DPI systems and that extend the DPI approach into agriculture-specific solutions.

3. Other countries are investing in agriculture-specific building blocks, most typically combinations of registries and data exchange solutions that should enable linkage with foundational DPI and other digital systems as their ecosystems develop.

Multiple countries are already taking steps to implement a DPI-approach in the agriculture sector, utilizing existing foundational DPI where possible and developing sector-specific building blocks as needed. The examples below represent a range of implementation contexts and solution complexity and will be important cases to learn from as DPI investments spread around the world.

Ethiopia

Digital Agriculture Roadmap: Developing a Digital Stack of Building Blocks to Support the Agriculture Ecosystem

The Ministry of Agriculture and the Ethiopian Agricultural Transformation Institute, in collaboration with the Gates Foundation and the World Bank, recently produced the Digital Agriculture Roadmap (DAR) 2025–2033.[28] The roadmap lays out a vision for a future digital agriculture ecosystem supported by a "digital agriculture stack," including building blocks for agriculture. The planned stack includes four layers: a user facing layer of applications and solutions, an integration layer, an analytics layer, and a data and content layer. The integration layer is supported by core building blocks for the agriculture sector, specifically a data stack with APIs utilizing open standards and consent mechanisms. The data and content layer includes foundational data sets and registries, including farmer profiles, unique IDs, and data on historical production, transactions, weather, soil, and market prices. The stack is also envisioned to leverage the foundational national ID program (Fayda), which will support farmer IDs, land administration, and rural safety net enrollment.

Priority initiatives in phase one of the roadmap's implementation, from 2025 to 2029, include components which correspond to foundational DPI and sector-specific building blocks: farmer profiles and unique ID, core data sets, and data exchange standards. Investments in key building blocks will be complemented by initiatives to strengthen the ecosystem, including governance and policy, digital infrastructure, human capital, physical infrastructure, agricultural markets, and innovation and technology.

Expected innovations: The foundational layers of the stack will support many use cases. The roadmap identifies 22 uses cases across six solutions areas: AI, supply chain, financial services, smart farming, pricing and market services, and extension and advisory. Key use cases include access to credit and insurance, track and trace for agriculture inputs, procurement and disbursement of inputs, and access to markets.

Implementation status: In development through 2029. Learn more here.

Honduras

TraceFoodChain: Leveraging Open Technology from AgStack for Traceability

A collaboration between the Alliance for Biodiversity and CIAT (International Center for Tropical Agriculture), Permarobotics, and the Linux Foundation's AgStack Initiative is enabling traceability across coffee supply chains in Honduras. TraceFoodChain is an open-source traceability tool built by Permarobotics that was through the AgStack initiative. The solution uses key building blocks of data standards like GS1 and EPCIS to enable interoperability of product details like source location, type of product, and other certifications useful for compliance with regulations like the European Union Deforestation-Free Regulation (EUDR). It's a low-cost option for SSPs and collectives to make it easier to meet requirements and participate in global markets.

Expected innovations: The TraceFoodChain product is one example of a tool built with interoperability standards to support traceability and regulation compliance by SSPs, growers' associations, and other value chain actors. The tool can be used offline and supports quick response (QR) codes and NFC. TraceFoodChain is integrated with Whisp to support deforestation risk assessment.

Implementation status: Stakeholders including The Honduran Coffee Institute (IHCAFE), Becamo, GrainChain, Confianza S.A., Beneficio Rio Frio, and Beneficio Rosales are field testing the solution in Honduras. Learn more here.

India

AgriStack: Farmer ID and Digital Registries for Input Subsidy Delivery, Loan Assessment, and More

The Ministry of Agriculture and Social Welfare in India is spearheading a DPI initiative in the agriculture sector known as AgriStack. AgriStack is a decentralized network of registries for agriculture, including core registries of farmers, location-tagged plots, and crop sown registries, with many additional supporting registries. The farmer registry utilizes a foundational Farmer ID linked to the Aadhaar identification system, enabling accurate identification and the ability to link farmer identities with land records and with other Aadhaar-linked services[29] - such as digital wallets to receive scheme payments. States maintain ownership of their data[30] and are responsible for instances in their state. They share data using the Unified Farmer Service Interface (UFSI), which acts as an API to provide data from the registries to other services.

Enabled innovations: The core registries of AgriStack represent essential registries for the agriculture sector to support a wide range of critical services. Access to accurate farmer identity, land, and crop production data can enable tailored advisory services and quick, digital assessments of creditworthiness for input loans for small-scale producers. Similarly, accurately identified farmers and ability to utilize digital wallets enables states and the federal government to more efficiently administer subsidy programs. Access to crop production data and other associated registries can also assist value chain actors with a range of crop management use cases, from procurement to warehousing and post-harvest management.

Implementation status: As of December 2024, the farmer registry includes over 3.7 million farmer IDs,[31] linked to Aadhaar numbers, with a goal of registering 60 million by the end of 2025. Learn more here.

***

Maha Vistaar: Public Network for Inclusive, AI-Enabled Advisory Services

OpenAgriNet (OAN) is a set of building blocks, packaged as a DPG, which consists of a unified, open network. It connects farmers and other value chain actors to everything they need: finance, advisories, inputs, markets, insurance, and government schemes. It utilizes a Beckn-based open network protocol to enable the exchange of queries and responses. On top of the Beckn-based network,OAN supports API-based access to an AI layer that offers personalized, real-time, voice-based support in local languages.[x] The package also includes a Model Context Protocol for integrating tools and APIs with the AI layer, which connects to LLMs to enable information to be translated into local languages. By providing an open, decentralized foundation for data exchange and access to local language models, OAN can foster agricultural innovation, enhance transparency, and reduce dependence on proprietary technologies.

Enabled innovations: The OAN solution will enable a range of query-based services including:

- **Real-time agricultural information** including weather and market prices.
- **AI-powered advisory services** to help farmers address crop health, pest control, and soil management challenges.
- **Training and discovery tools to assist** farmers in accessing best practices and finding relevant government schemes, ensuring farmers can make informed decisions.

Implementation status: Launched in Maharashtra state-wide as Maha VISTAAR (Virtually Integrated System To Access Agricultural Resources) in May 2025. A private network called Unified Krishi Interface is operational in Nashik, Maharashtra. OAN also offers a sandbox environment to enable stakeholders to explore collaborative solutions. Learn more here.

***

ADeX: Agriculture Data Platform for Data-Driven Innovation

The Agriculture Data Exchange (ADeX), an initiative of the Government of Telangana, exemplifies the use of data exchange building blocks in agriculture. ADeX is a data sharing system that aggregates

[x] See "Digital Open Networks" in Section 6 for more details on how this design works.

and curates core agricultural datasets, including soil health and crop data, into the same environment as weather data and satellite images, based on standard protocols. This creates a single, secure space to view and analyze many different types of data relevant to agriculture services. ADeX strongly emphasizes data standardization and interoperability. It employs established data specifications such as JavaScript Object Notation (JSON) and is the impetus behind the AgriJSON schema to enable data interoperability and standardization across agricultural datasets. The platform requires standards-based data formats and APIs to ensure seamless integration and exchange of data, which is critical for enabling innovation and reliable data-driven solutions in the agriculture sector. The Agriculture Data Management Framework (ADMF), launched alongside ADeX, provides governance and guidelines to ensure data protection, consent management, and quality, embedding these principles into the platform's operations.

Enabled innovations: The first use case focuses on farmer financing, where the platform provides detailed information about farmers, their farmland, and government direct benefit transfers received. This promotes financial inclusion and fosters empowered and innovative solutions to agricultural challenges through enhanced data access and stakeholder collaboration. It will also support innovations including electronic farm records, soil health advisories, pest prediction, and farm machinery demand forecasting.

Implementation status:ADeX was initially developed for Telangana State in India and currently offers a sandbox environment with data relevant to two use cases in Telangana. Learn more here.

***

Tamil Nadu Matching Grant Portal: Foundational Digital Identity and Authentication for Inclusive Rural Finance

The Government of Tamil Nadu, under the Vaazhndhu Kaattuvom Project and Tamil Nadu Rural Transformation Project (TNRTP), established a Matching Grant Portal (MGP) with support from the World Bank. This portal serves as a phygital (physical + digital) financing marketplace and loan management system involving over 15 public and private sector banks. The system leverages foundational DPI building blocks such as India's national foundational ID (Aadhaar) and eKYC verification based on Aadhaar authentication. The entire credit assessment process is digital and automated, drawing information from various sources such as credit bureaus via API connections.

Enabled innovations: This program leveraged foundational DPI for a financial lending program that aims to promote rural enterprises, which include producer collectives, individual SSPs, and agri-businesses. The program improves loan repayment and encourages mainstream financial institutions to participate in lending to these groups. To do so, the program offsets the risk of default by offering the borrower an incentive for repayment.[32] For every 70% of the loan repaid, the borrower will receive a 30% waiver of the remaining amount to a maximum of INR 40 Lakhs (equivalent to ~US $45,000), effectively acting as a matching grant.

Implementation status: This initiative has supported over 1300 individual and collective enterprises [33] since 2017, enhancing financial inclusion and scalability in rural finance. Learn more here.

***

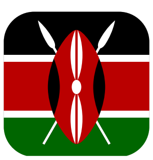
Bihar Krishi: State-Level Building Block for Integrated Farmer Services

To address systemic challenges faced by small and marginal farmers in Bihar, India, including fragmented service delivery, limited access to markets and inputs, and climate vulnerability, the Government of Bihar launched Bihar Krishi, a unified digital platform aimed at streamlining agricultural service delivery developed with support from the Gates Foundation and implemented by MicroSave Consulting (MSC).

Bihar Krishi is built on sector-agnostic and sector-specific building blocks, such as farmers and landholdings registries and national digital ID (Aadhaar), and offers over 16 interconnected modules. These include AI-enabled advisories, weather alerts, real-time mandi prices, access to state and centrally sponsored agricultural schemes, financial services, and grievance redressal mechanisms. While designed as a mobile-first solution with intuitive user interfaces and multilingual functionality, the platform allows users with low literacy and without phones to access services through agents. The platform facilitates interoperable service delivery by connecting farmers with verified input suppliers, financial institutions, and public schemes. By digitizing touchpoints across the agricultural value chain, Bihar Krishi aims to improve productivity, financial inclusion, and resilience at scale.

Expected innovations: AI-powered advisories, integration of public schemes and private sector services, access to financial services, mobile-first design, assisted use through agents for low-literacy or no-phone users.

Implementation status: As of 2025,[34] the platform is operational across all 38 districts of Bihar, serving over 500,000 farmers, of which 25% are women. It is integrated with more than 50 government schemes and continues to expand its user base and functionality. Learn more here.



Kenya

KALRO: Digital Registries and Agriculture Data Exchange for Tailored Advisory Services

The Kenya Agricultural and Livestock Research Organization (KALRO) is a publicly-funded research organization that was established under the Kenya Agricultural and Livestock Research Act of 2013 to provide a comprehensive legal and institutional framework for the coordination, promotion, and regulation of agricultural research in Kenya. Its creation marked a milestone in the Government of Kenya's efforts to reform the National Agricultural Research System by consolidating various research institutions into a single, efficient entity. KALRO has a long-standing history of generating and managing scientific research data to support agricultural development in Kenya. Over time, this has evolved into the systematic collection and curation of comprehensive datasets across critical domains including weather, crops, livestock, soils, climate, and farmer registries.

The platform is built with interoperability at its core, utilizing open APIs that conform to representation state transfer (REST) principles (or “RESTful APIs”) supporting output in standard JSON format to enable integration with digital advisory tools and services across agricultural value chains. Data can be shared with select public and private actors using memoranda of understanding (MoU), non-disclosure agreements, and other data-sharing agreements per terms outlined in partnership agreements and in compliance with Kenya’s Data Protection Act. For example, data has been shared with the National Fertilizer Subsidy Program and the Kenya Ministry of Health. In the private sector, access has been provided to agri-tech businesses providing last mile extension services. KALRO is developing available foundational DPI (e.g., farmer digital identities) in addition to their registry data to inform their advisory service as well as integrations with several other agriculture and weather services, such as the Digital Climate and Advisory Service.

Enabled innovations: In alignment with national priorities, KALRO leads the development of use cases for the data such as the Kenya Agricultural Observatory Platform (KAOP), which provides actionable insights on Good Agricultural Practices (GAPs), Climate-Smart Agriculture (CSA) and seasonal weather forecasts. The platform supports the co-development of Digital Climate Advisory Services (DCAS) and Suitable Planting Windows (SPW) in collaboration with stakeholders. These advisories are customized to agro-ecological zones, and crop calendars are disseminated through inclusive digital channels including SMS, Unstructured Supplementary Service Data (USSD), agri-advisory call centers, web portals, and mobile applications. Furthermore, datasets from the platform are consumed by various digital tools such as the KALRO Selector app, crop suitability maps, and the Technologies, Innovations, and Management Practices (TIMPs) knowledge repository. Such use cases play a pivotal role in strengthening Kenya’s agricultural digital ecosystem, supporting data-driven policy formulation, and enhancing the delivery of farmer-centric, climate-smart, and market-oriented digital public goods.

Implementation status: The KALRO team maintains a range of core registries, including the farmer registry, soil registry, market registry, commercial firms, cooperatives (savings and credit cooperative organizations, or SACCOs, and farmer producer organizations, or FPOs), agro-dealers and stock list registry, weather registry, agronomic registry, and call center feedback registry. The farmer registry held on the Kenya Integrated Agricultural Management Information System (KIAMIS)[35] includes over 80 percent of the approximately eight million farmers in Kenya, of which more than 75 percent receive tailor-made advisory services. Learn more here.

Lao PDR

OpenSPP: Digital Farmer Registries and Agriculture Data Exchange for Targeted Assistance in Irrigation and Watershed Management

In the Lao People's Democratic Republic (Lao PDR), the Department of Irrigation of the Ministry of Agriculture and Forestry (MAF) supports a dynamic, digital system that will enhance their ability to target programs and efficiently manage and coordinate activities. While Lao PDR does not have existing digital identity, payments, or data exchange systems, the country recognizes the challenges of data fragmentation and are supportive of using a DPI approach to overcome it. As an initial effort, the MAF is piloting one of the first dynamic, digitized systems in Lao PDR, a digital farmer registry implemented using OpenSPP, a DPG originally utilized to facilitate delivery of social protection payments.

OpenSPP uses an API design to support a wide range of integrations between the farmer registry and other systems. OpenSPP can support integration with other registries, for example, social protections registries or farmer land registries, as well as payment systems and data services – making it easy to utilize data from other DPI building blocks or API-accessible applications whenever they become available. OpenSPP already supports integration with ID and civil registry systems, such as the Modular Open Source Identity Program (MOSIP), and Open Government-to-Person (OpenG2P) for payments. This makes it interoperable with those systems if they are implemented in Lao PDR in the future.

The digital farmer registry in Lao PDR accesses data from existing systems, building on what already exists. It brings data from existing databases together in a comprehensive, dynamic registry that can be regularly updated and that can facilitate data exchange with other systems. The digital farmer registry in Lao PDR will also be able to access data services outside the agriculture ministry, for example, integrating GIS data to enhance the ability of the MAF to geographically target activities.

Expected Innovations: The OpenSPP team is working with MAF to integrate the farmer registry into several irrigation and watershed management projects, linking farmer, household and community data with other data sets to improve targeting, management, and monitoring of project activities. It is incorporating data from a small set of initial projects, with the potential to grow to support additional use cases including farmer loans, disaster risk mitigation, and nutrition use cases.

Implementation status: Pilot stage, implementing in 2025. Learn more here.

Pakistan

SMART-Punjab Program-for-Results: Leveraging Foundational Digital Identity for Agriculture Subsidy Disbursement

In Pakistan, the Strengthening Markets for Agriculture and Rural Transformation in Punjab (SMART-Punjab) Program-for-Results (P4R) operated from 2017-2023 and utilized digital farmer registries to improve the reach of services and promote transparency in the use of publicly funded agricultural subsidies. The Punjab Agriculture Department developed a comprehensive digital platform that acted as a centralized information repository and management system. This platform integrated various data sources including farmer registrations (via mobile apps capturing farmer and farm attributes), soil health data, market information, weather data, and subsidy-related information.

Data sharing and interoperability were facilitated through standardized APIs and digital workflows embedded in the management information system (MIS), which support extension services and subsidy disbursement processes. This enabled communication between farmer registries and subsidy databases, ensuring data consistency and timely updates. Following the Punjab Agriculture Policy 2018, multiple systems including farmer registries and subsidy databases, were integrated with the national digital identification system run by the National Database and Registration Authority (NADRA) and the Punjab Land Revenue Authority (PLRA) to ensure accurate identification and verification of farmers for subsidy disbursement and other agricultural services. Thus, national identity verification and mobile-based farmer registration apps ensure that beneficiary identity and farm details are authenticated and linked across databases, supporting secure and consent-based data sharing.

Enabled innovations: The program was able to share data across subsidy and farmer registry data systems to efficiently target agriculture input and insurance subsidies. The intervention relied on several digital systems and technology components in the broader ecosystem as well, using farmers' cellular phones to deliver input subsidies, extension messages, and crop insurance payments.

Implementation status: The program reached approximately 200,000 farmers in Punjab province during its operation. Learn more here.

Summary

Many of the use cases, particularly those developing building blocks for the agriculture sector, are relatively early in deployment. While there are multiple initiatives in-progress across India, these are often within specific states and represent slightly different architectures and approaches to delivering similar services. These case examples reflect early-adopters, with potential for further ecosystem development to achieve widespread country-level adoption. These issues are explored further in following sections. The World Bank Group is working on a compendium of examples from various countries to be published soon.

SECTION 06

Example Architecture Archetypes for Agriculture Building Blocks

Key Messages

1. Technical implementation of building blocks in the agriculture sector is context specific.

2. Multiple approaches to exchanging agriculture data between different building blocks exist, including those that utilize standard APIs and those that use open-network protocols.

3. Within a country context, multiple different approaches may be used by different components, potentially across different states or sub-national units. The use of shared data standards and exchange protocols will minimize fragmentation even as different parts of the ecosystem develop on different timelines.

As the country examples in Section 5 show, leveraging foundational DPI and relevant sector-specific building blocks can reduce data fragmentation within and across sectors. This section presents archetypical architectures that can support successful integration of agriculture building-blocks with foundational DPI.

For example, implementations of foundational, national-scale DPI such as digital identity benefit from an Enterprise Architecture (EA) approach, where the enterprise is defined as the entire digital landscape of a country. For sector-specific investments especially, coordination and alignment with broader national digital strategy and national EA initiatives can help extend the use of specific building blocks beyond one sector, where relevant (e.g., the use of crops-sewn registries for health and nutrition use cases, or pest surveillance data services for climate use cases). Further, it can help reduce fragmentation between sectors. This overarching cross-sectoral architecture enables the identification of common components and data flows.

While DPI architecture draws from EA principles, it balances the centralized governance approach with decentralized, market-driven innovation. Open protocols and standards enable interoperability without the need to define how applications are built, allowing a diverse set of public and private sector implementors to build modular components that work with foundational, centrally governed infrastructure. This is starting to happen through the examples previously discussed.

At the same time, implementers are approaching the design of data exchange and its connection to foundational DPI in different ways. Consultation with implementers and review of existing products show that the specific approach to implementing building blocks as part of a country's DPI and complementary sectoral systems varies within and across countries. Each implementation has a unique context, dependent on existing hard infrastructure and foundational DPI, the maturity of the sector, workforce capacity, availability of finances, and country regulations and broader IT governance structures. Rather than one common reference architecture, this section describes three high-level conceptual architectures informed by existing implementations. Together, they offer implementers and developers a general orientation to options for connecting building blocks to each other and to foundational DPI elements where they exist.

The first archetype, the **Centralized API Gateway** approach, is a more traditional approach of centralized services that communicate via APIs. In an ideal scenario, data would be exchanged through an interoperability layer providing standardized interfaces, and these data would be formatted according to common standards. In practice, each service often has custom API interfaces and data formats. Many DPGs, including OpenSPP, participate as DPI building blocks in this way.

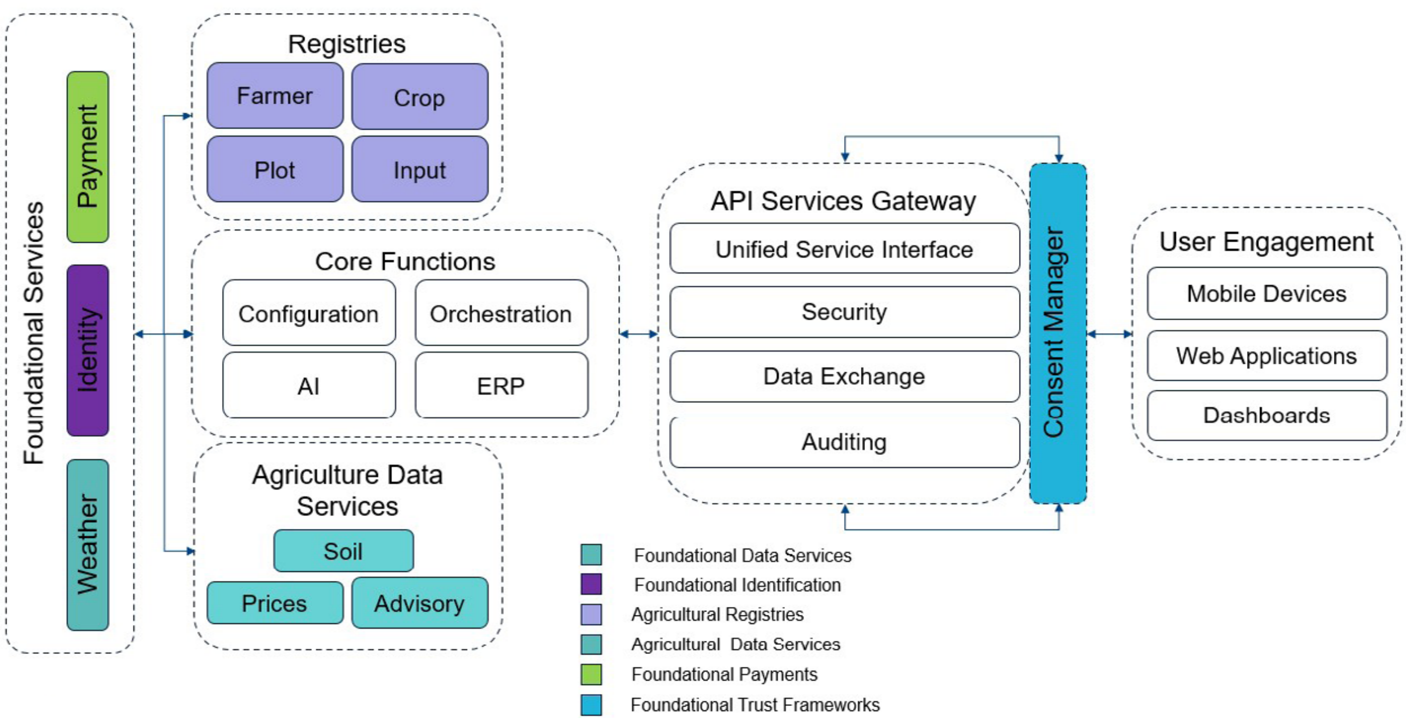
A second, newer approach, **Digital Open Network**, leverages open network protocols. This approach has been used in eCommerce to expand the set of supply-side services in an open and trusted environment. Multiple suppliers of products, services, and information are able to register with the network and access demand-side consumers. This approach has been adopted in the agriculture sector, most notably by OpenAgriNet, using the Beckn protocol.

The third archetype, a **Central Directory to Decentralized Registries**, describes how federated data can be linked across sub-national and organizational boundaries. This caters for scenarios where data are owned, housed, and curated by states or private-sector organizations in different systems, but are linked at a central level. Access is provided through a consent layer and a common or universal service interface. AgriStack links farmer registries across many states in India in this way.

Centralized API Gateway

Across the digital agriculture landscape, many platform architectures reference an API services layer, interoperability layer, or services gateway. This archetype, illustrated in Figure 6, details common building blocks and a generalized way that data are exchanged via APIs.

Figure 6 - Centralized API Gateway



Demand-side users interact with the platform through an **API Services Gateway**. The gateway can be simply a set of APIs, or a more advanced information exchange or interoperability layer (also referred to as a services gateway). Components of the architecture exchange data with each other in a similar fashion, either through APIs or through an interoperability layer.

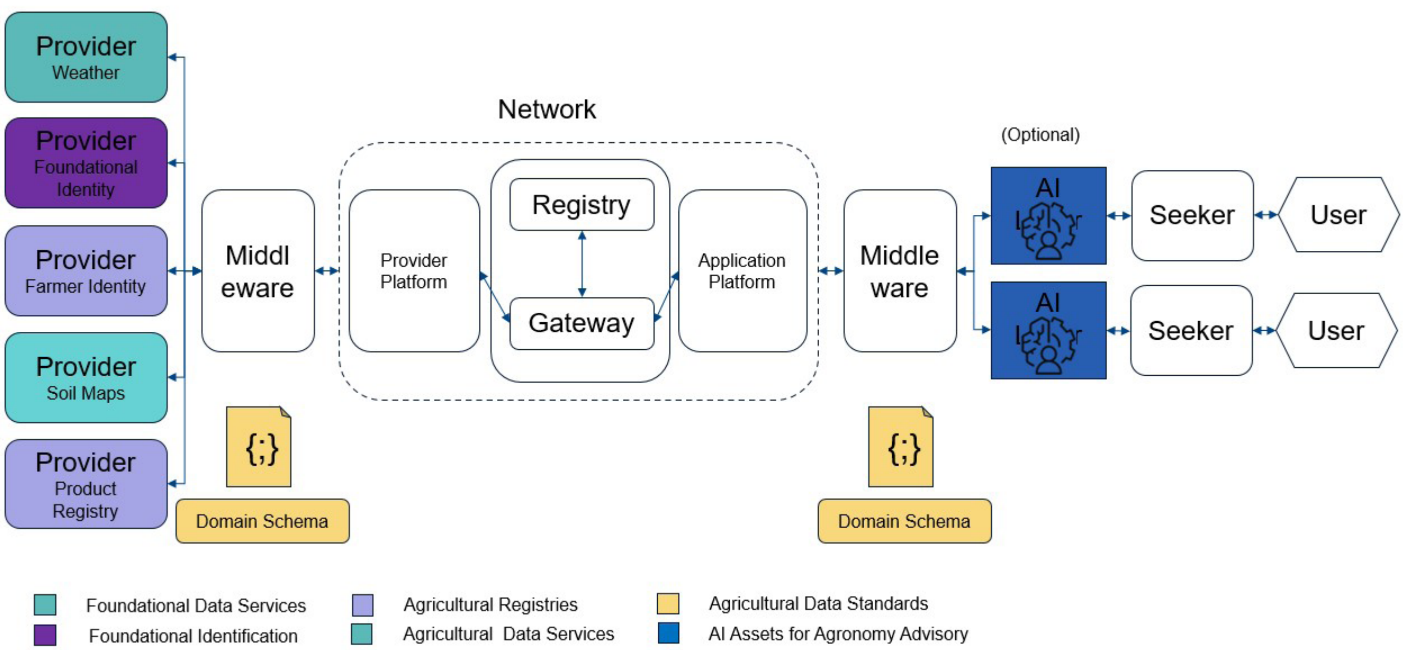
The API Services Layer component generalizes the various gateways or service interfaces. This component commonly includes capabilities for secure data transfer, auditing and logging, and data exchange through a common set of APIs in a **Unified Service Interface.** The **Consent Manager**, closely coupled to the API Services Layers, enables data owners to explicitly allow or deny access to specific information. Consent is granted by data owners through web or mobile applications, or via basic text or voice-based mechanisms (e.g. USSD, SMS, or IVR), using digitally signed and timestamped permissions that are time-bound and can be revoked at any time.

Core Functions of the platform consist of business services which orchestrate requests and encapsulate business logic and provide enterprise resource planning (ERP) capabilities. Integration with other building blocks (**Data Services, Registries** and **Foundational Services**), is via API services provided by each building block, which may be internal to the platform or external components of the private or public sector.

Digital Open Networks

The use of Open Network Protocols (Figure 7) is common in the eCommerce space and increasingly used in the agricultural sector. These enable and democratize the supply chain, giving farmers and other users access to data, products, and resources from multiple providers.

Figure 7 - Digital Open Networks



Open Network Protocols enable users (e.g., farmers) to access content, products, and services from multiple providers using the same front-end application.

Seekers are applications, services, or agents that initiate a search or transaction. They communicate via RESTful APIs (typically JSON over HTTP) using standardized OpenAPI specifications. Requests are packaged using agriculture-specific controlled vocabularies for better semantic matching. Agriculture-specific data standards, such as AgriJSON, can be used to structure payloads within API messages.

Requests from the Seeker (and subsequent responses) can optionally pass through an **AI Layer**, which can enhance searches using LLMs and natural language processing (NLP) models to determine the user intent, link queries to provider offerings, translate queries and responses from one language to another, and enhance searches with recommendation engines based on domain knowledge graphs and usage patterns. While not shown in the diagram, the AI Layer often utilizes vector databases for semantic similarity searches.

Middleware components communicate with the Seekers and Providers to transform data formats, orchestrate multi-step transactions and business logic, and enable interoperability between protocols.

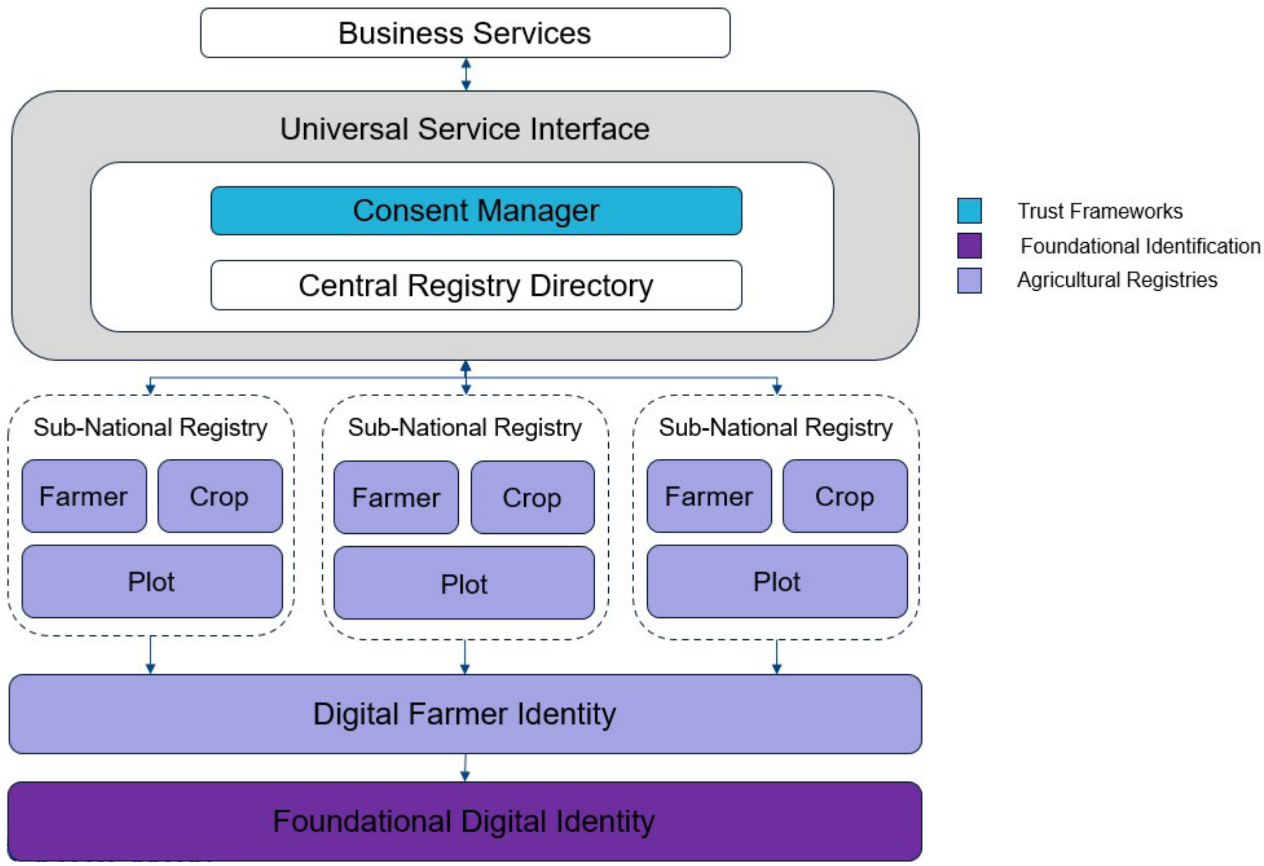
The **Network** Layer is the component which enables discovery and communication across a decentralized set of services, allowing participants to discover, communicate, and transact without a central authority. The **Registry** is a trusted, open directory where all network participants (providers, gateways, apps) register their capabilities and endpoint information, enabling discovery across the network. The **Gateway** acts as a network router, receiving requests from application platforms and efficiently locating and forwarding them to the right provider platforms, using metadata from the Registry. The **Provider Platform** exposes APIs that offer services, products, or information in compliance with Open Protocols, responding to search, order, and fulfillment requests. Multiple Providers may interact with the provider platform, each offering relevant services to expand and democratize the offering to the user. The **Application Platform** is the interface through which Seeker applications interact with the network, for example submitting search requests or performing transactions. These standardized and digitally signed messages are transmitted through the Gateway to Providers, which respond with appropriate information.

The **Domain Schema** defines a standardized set of data models, for example a product, order, quote or payment, which represent the core business concepts across different sectors, allowing participants to structure information consistently to facilitate interoperability. OpenAgriNet has adapted and expanded Beckn domain schemas for the agricultural sector, introducing entities such as farm services, harvest logistics, crop types, and others.

Central Directory to Decentralized Registries

While some data, like national identification data, have historically been designed through a central, government-led governance model, there are many contexts where relevant data are housed and governed in a decentralized model. Sector-relevant data are often contained in sub-national and private-sector platforms. An emerging approach in contexts like these is to define data exchange standards and API interfaces and implement central directory services that link data in decentralized registries. A common interface allows data in the central directory to be queried, providing an overarching consent layer. (Figure 8)

Figure 8 - Decentralized Registries



Sub-National Registries are managed and governed by sub-national organizations, often state or provincial governments. The design and technology is not centrally governed, and they may be in use before a national DPI-platform is conceptualized and implemented. Thus, these registries, which contain the core set of full data collected by the owning organizations, may be developed using different software stacks with non-standard data schemas.

A **Digital Farmer Identity** provider is a centralized building-block which issues a unique farmer ID to each farmer in the sub-national registries. These IDs may be validated against a national identity provider upon creation.

Sub-National Registries are linked and accessed through a **Central Registry Directory**, which contains identifiers and metadata that map records back to the source registries. Data queries are routed through a **Consent Manager** which enforces data access rules.

Data are exchanged between the sub-national and national registries via a **Universal Service Interface**, a set of APIs and defined data schemas that enable standardized interoperability between government agencies, financial institutions, and private sector companies. The Consent Manager is integrated with the Universal Service Interface, allowing data owners to grant or deny access to data that is shared between source registries and the directory, and to data that is utilized by the ecosystem of Business Services, which includes public and private sector organizations.

Architecture Summary

While distinct, these architecture archetypes are not mutually exclusive and may be used together. For example, a decentralized registry architecture can be used with both Centralized API Gateway and Digital Open Network approaches, and national DPI may consist of both centralized APIs and Open Networks.

Among the three archetypes, the Centralized API Gateway is the simplest to implement from a governance and technical perspective, as it involves fewer coordination points, centralized control over data exchange standards, and straightforward integration between components. However, this simplicity can become a limitation at scale, where sectoral silos and rigid interfaces hinder innovation and extensibility. In contrast, Digital Open Networks are emerging as a transformative model in the DPI for agriculture space, offering greater flexibility, inclusivity, and scalability by enabling many-to-many interactions through open protocols. This approach empowers a broader ecosystem of providers and innovators but requires a mature digital infrastructure, strong governance around trust and discovery, and the establishment of domain-specific standards. Decentralized Registries address the practical realities of fragmented data ownership across sub-national and organizational boundaries. They offer autonomy and localized control, but add complexity in ensuring data consistency, semantic interoperability, and discoverability. As countries advance their digital agriculture strategies, hybrid models are emerging, blending centralized control where necessary with decentralized participation and open-network innovation to maximize interoperability, inclusivity, and resilience in evolving DPI ecosystems.

SECTION 07

Limitations of the Current Implementation Context

Key Messages

1. While there is growing support for the DPI approach, the current implementation contexts across LMICs present numerous limitations.

2. High frequencies of bespoke registries increase the need for decentralized architectures that do not assume a central repository.

3. Use of common data standards, exchange protocols, and vocabularies is currently limited, as is the quality of many core data sets.

4. Few AI assets are currently developed as building blocks ready for innovators to use.

5. The ecosystem for DPI in the agriculture sector is early in its development and will need time and continued investment to support robust implementation of agriculture-specific building blocks.

As more countries implement foundational DPI and pursue a DPI approach within the agriculture sector, there will be growing demand for robust, mature building blocks available for use. However, the architectures and case examples above are emerging in a nascent landscape, and, as discussed further in this section, numerous challenges will need to be addressed to realize the full potential of DPI and building blocks for the agriculture sector.

Working with Centralized versus Federated Architectures

Many countries commonly have multiple registries of the same entity. For example, a farmer registry may be managed by different organizations or be federated by district or state. While one master registry would be simplest, it is often impractical given how decentralized these data already are in many countries. Further, it is becoming less desirable to centralize data in one place, particularly if it contains sensitive information. Centralized approaches also introduce dependencies on centralized IT support, governance, and development resources, which may limit flexibility and response needs. Instead, a common pattern is to have a central component that links these federated registries to provide a master list. This decentralized approach is reflected in the AgriStack architecture, for example.

Decentralized architectures will likely be more feasible and consistent with data governance frameworks, as data are owned by multiple public and private sector organizations. This increases the importance of coordination around data standards and schemas to facilitate sharing between, for example, the numerous distinct registries that make up a national superset of entities. Decentralization can also introduce other challenges, such as linking records across registries, deduplication of records, and reliance on network connectivity.

To facilitate data exchange with other data systems, registries should have defined open API interfaces and, ideally, consume and produce data in a common, agreed standard. These standards are not yet mature in the agriculture space but are beginning to develop, as discussed below.

Limited Adoption of Common Data Standards, Protocols, and Exchange MechanismsArchitectures

In the agriculture sector, there are a few standard data schemas that have been tailored for agricultural data. AgriJSON is one such standard affiliated with the ADeX data exchange platform. This is an adaptation of the JSON schema that provides domain-specific structure and schema to support exchange of data common in the agriculture sector, such as crop boundaries, crop types, soil condition, and weather types in a machine-readable way. However, AgriJSON is not yet widely adopted, and data-sharing tends to be point-to-point, via custom API interfaces.

AgroXML, an adaptation of Extensible Markup Language (XML) schema for task documentation, is another standard used within the sector. However, AgroXML is more narrowly focused on task documentation for machinery used in precision agriculture and is more common in European operations than LMIC contexts.

Data exchange protocols specific to agriculture data are more nascent. Digital Green's FarmStack protocol is intended to facilitate exchange of agricultural data which is based on the International Data Spaces Association (IDSA) ontology and used in Ethiopia and Kenya, but is not widespread. Other stakeholders, through the OpenAgriNet Community, are working on adaptations of the ecommerce protocol Beckn to accommodate queries related to agriculture advisory, as seen in the Maha-Vistaar and Kuza cases above.

Ongoing initiatives to create greater coherence in standards used in agriculture include the Digital Integration of Agricultural Supply Chains Alliance (DIASCA) and the Digital Convergence Initiative (DCI) (see Section 10 for more details). As standards mature, there will be a concurrent need to strengthen the capacity of a software developer workforce that is comfortable with the relevant standards and protocols.

Variation in the Structure of Data Exchange. The structure of data sharing mechanisms also varies. As noted earlier, shared interoperability layers and data exchange mechanisms are key to introducing effective data sharing capabilities, robust consent mechanisms, audit capabilities, and enhanced security features. Yet, despite the example architectures for data exchange explored above, these remain relatively rare in the broader landscape of digital agriculture practice. More often, data is exchanged via point-to-point interfaces, without a central data exchange mechanism or open network design.

Limited Quality of Existing Agricultural Data

While there are multiple examples of data exchange platforms for core agricultural data sets as well as data held in various registries for agriculture, their success relies on both the quality and utility of data, as well as the structure and ease of data sharing.

Data Quality. Across LMIC contexts today, the extent and quality of agriculture-relevant data is highly variable. While some countries have national data initiatives for weather models and soil maps, for example, the more granular data needed for tailored advisory use cases tend to require innovators to collect data themselves to augment more general sources.

Data sources containing details on local climate, soil, and market conditions also have challenges with quality; for example, soil data quality suffers from a lack of standards[36] and inclusion of errors that limit its utility for high-quality advisory services. Data related to pest surveillance can be impacted by errors[37] from inaccurate identification[38] or be of limited use due to insufficient data on rare pests[39]. Market data can be unpredictable for small-scale producers due to pricing instability[40] and volatility[41]. These inherent limitations underscore the value of making root sources of data available through APIs, enabling stakeholders to access whatever data is currently available, rather than relying on static snapshots in databases. The more available and usable the data is, the more incentive there may be to enhance the quality and completeness of data over time.

For public services that do collect data at national and local level, data sharing norms and regulations continue to be a challenge. KALRO has invested significant time in working through data sharing efforts to first garner buy-in and then comply with local data sharing regulations to support data sharing across a range of national agriculture registries.

Few Existing AI Assets

As noted above, there are few such assets in the current landscape that fit the definition of a building block. Domain relevant data repositories for training AI models face many of the same challenges as core data services with respect to data quality and accessibility. Many innovators working in AI-based advisory have had to compile their own content repositories, either investing time curating from scratch or supplementing global repositories with more locally relevant content to train advisory models that respond appropriately to local queries. Collecting relevant data for common advisory questions can be time-consuming, and it can be challenging to navigate data-sharing regulations, only to gain access to data that may not have the anticipated value or relevance.

As more data becomes available through registries and other data services, they may start to support AI-enabled use cases. However, collections of multi-modal content that are annotated and formatted will likely require a distinct initiative to curate. Presently, actors holding large amounts of farmer data or advisory data rarely have incentives to contribute that data to robust repositories of local content that would be open to others.

Small language models that capture the nuance and specific vocabulary used in communicating agriculture practices are another potential building block that could serve many agricultural use cases and reduce costs associated with leveraging larger models. Given that these linguistic nuances change rather slowly, investments in developing and maintaining one such model that performs well and meets governance characteristics of DPI could then be further fine-tuned and adapted for many use cases involving digital communication to farmers. However, these, too, are only starting to emerge. Several digital agriculture innovators are developing SMLs for agriculture (e.g., Dhenu.ai, Digital Green), though none would yet be considered building blocks, given either closed source or small scale use.

Similarly, while there are multiple large language models offering sector-agnostic language translation, most are privately owned and lack public accountability mechanisms. Several privately developed and governed LLMs (e.g., llama, ChatGPT, Claude) are also API-accessible and sometimes leveraged for sector-specific language translation functions. In contrast, India's Bhashini language model is more aligned with DPI characteristics given its public backing, API-accessibility, and growing use by innovators. However, the cost of inference of LLMs each time the model is used may eventually drive demand for SML building blocks that are more financially sustainable for innovators.

Finally, Like Q&A pairs for general LLMs, a curated set of Q&A for agriculture advisory could also eventually be a shared data asset that would create a baseline for performance evaluation of either general LLMs or SLMs that will be utilized for advisory tools. This is essentially a specific type of content that would need to be a curated data set, informed by a trusted multi-stakeholder group of sector experts and innovators, developed in accordance with open data standards and formats, and API accessible. These are not currently available as DPGs but may have increasing value in enabling comparability to different advisory models as AI-enabled tools for agriculture continue to be developed.

Summary

The current landscape is still developing. Robust DPGs for agriculture are only starting to become available; implementer communities working on key challenges like standards development and data exchange design are relatively young, and while momentum and some collaborative investments are occurring, there is not yet a clearly established organizing body driving collaboration within and across ecosystems. There is ample opportunity for governments, implementers, and private sector actors to engage and shape the future development of DPI-enabled ecosystems for agriculture.

SECTION 08

Beyond Technology – Strengthening Ecosystems for Effective Implementation

Key Messages

1. How countries implement a DPI approach is critical for mitigating risks that can otherwise result.

2. Key considerations to avoid negative outcomes include:

    - Ensuring collaboration with whole-of-government information and communication technology (ICT) initiatives and sector-agnostic ICT stakeholders to avoid creating sectoral silos.

    - Supporting market shaping and private sector engagement to ensure broad participation in DPI-enabled ecosystems.

    - Planning for financial sustainability and sound business models to sustain key DPI components and sector-specific building blocks.

    - Investing in building an evidence base for DPI, including sectoral outcomes, and return on investment.

    - Mitigating risks of exclusion that DPI-enables services may create.

    - Protecting privacy and ensuring security of data shared within and across DPI systems.

Beyond the technical design considerations, implementing a DPI approach in the agriculture sector requires attention to and investment in the ecosystem into which it is introduced. The approach to implementation is as important as the building blocks themselves. Investments that support coordinated governance, financial sustainability, market-shaping, monitoring, and continuous efforts to prevent exclusion are critical to ensuring that the implementation of DPI and agriculture-specific building blocks succeeds in growing more inclusive, efficient, and competitive agricultural ecosystems. This section explores multiple dimensions of ecosystem development important for successful DPI and building block implementation. Where relevant, it includes additional details from consultations with stakeholders involved in the case studies described in Section 5.

Cross Sectoral Governance: Avoiding Silos between Sectors

Coordination across ministries and stakeholders is critical. Where ministries of agriculture may be moving faster than sector-agnostic DPI initiatives, or where the sub-national level is moving faster than national level activities even within a sector, countries risk sector-specific building blocks becoming siloed while waiting for cross-sectoral initiatives to develop. The risk of recreating silos is particularly high if broader government engagement and whole-of-government EA efforts are not occurring in a country. In Lao PDR, for example, there is no foundational DPI for the OpenSPP team to connect to when developing digital registries. Although they built to open standards to be ready for integration with relevant DPGs like MOSIP and OpenG2P, registries for the agriculture sector will be unconnected until other investments are made. Engaging in development of cross-sectoral policy and political relationship-building across sectors and national and sub-national levels will be important to leverage sector-specific investments to drive interest and commitment in creating foundational DPI components. Countries may consider setting up dedicated units or inter-agency teams to lead implementation. A "mission-mode" approach, as used in India's Digital India and JAM trinity (Jan Dhan, Aadhaar ID, Mobile) initiatives, can provide focus, accountability, and agility to drive cross-sectoral DPI deployment.

Proposed approaches:

- Engage other line ministries, and, if it exists, the national ministry or presidential office for information and communication technology (ICT) or digital transformation to discuss envisioned building blocks for the sector.
- Invest in partnerships and socialization to facilitate political buy-in of key stakeholders across levels of government within and across sectors.
- Adhere to open standards and building APIs to ensure that integration with future building blocks is possible.
- Support national enterprise architecture efforts to create a reference architecture and normative standards for how sector-specific systems can connect to and exchange data with other governmental systems, with appropriate controls.

- Create key performance indicators around involvement of other parts of government and/or identification of potential use cases for the building block in other sectors (e.g., applications relevant to agriculture and health, for example) or sector-agnostic applications.
- Socialize plans for building block development with leaders from other parts of government at DPI or DPG-related events.

Cross Sectoral Governance: Avoiding Silos between Sectors

Market shaping and collaboration with private sectors actors can facilitate widespread participation in a DPI-enabled ecosystem. Public-private partnerships can encourage private sector use and participate in shaping DPI-enabled ecosystems. At the same time, they enable public sector stewards of DPI to leverage innovation, efficiency, and market reach of private sector actors. Market shaping and partnerships designed to incentivize private-sector engagement can help overcome potential deterrents to private sector engagement with DPI-enabled systems.

Illustrative Market Shaping Initiatives

- Public sector offering quality assurance and standards compliance for data sets made available through DPI platforms.
- Public sector guaranteeing demand for agricultural products offered through open discovery networks and marketplaces.
- Conditioning supply chain contracts on registration of products and use of common traceability standard.

For example, bespoke registry systems might require significant efforts to transition to API-accessible systems. The process of migrating data, adjusting data formats, and other configuration requirements may lessen the likelihood that stakeholders fully step away from existing solutions. In contexts where there are existing legacy systems or sub-national equivalent structures, stakeholders are likely to need clear business cases and assurances of government capacity, reliability, and commitment to maintaining DPI systems in order to adopt them or participate in a federated network initiative.

Similarly, contributing data to content repositories or platforms that follow building block design principles may not be beneficial to organizations that have invested in collecting such data independently. This is particularly relevant if that data offers a competitive advantage. Further, the return on investment in data repositories can be relatively long, which disincentivizes business-minded stakeholders from contributing resources or highly valuable assets to it. Public sector actors could offer services to make data available through common platforms, e.g., quality assurance or compliance with standard formats, which enhances usability and lowers burden on data provider to invest in similar activities.

Business models for data infrastructure are a key pillar in the United Kingdom Commonwealth Secretariat's National Agriculture Data Infrastructure initiative. Its inclusion recognizes the need for business models that can support both the initial investment building blocks for core data services, registries, and market discovery networks, as well as the costs of maintaining them. For DPI-enabled ecosystems to include significant private sector engagement, there will need to be consideration for market incentives that will encourage participation by actors who might otherwise establish or continue to use separate systems.

Proposed approaches:

- Socialize clear value propositions for different stakeholder groups to utilize building blocks for their solutions rather than creating bespoke solutions. Potential advantages include: increasing market size achieved when registries and market discovery networks are more inclusive, improved quality of function of DPI components relative to bespoke solutions, offset maintenance responsibilities by utilizing a shared, commonly supported building block.
- Adopt market shaping initiatives to encourage adoption of newly available building blocks for the agriculture sector.
- Engage value chain stakeholders early to understand market implications of adopting a common building block into current processes.
- Develop targeted marketing campaigns to encourage farmers, wholesalers, and retail (agribusiness and value-chain actors) to use DPI-enabled services.
- Invest in building blocks for the sector sufficient to ensure they are high quality, easy-to-use, and offer a high-value alternative to other options.
- Include key performance indicators around inclusion and participation from diverse stakeholders, including public and private stakeholders, and SSPs as well as larger value-chain actors.

Financial Sustainability and Business Models Associated with DPI-Enabled Services

Cost considerations and financial sustainability models are an increasingly relevant consideration for both foundational DPI and sector-specific building blocks, particularly where DPGs and open-source software may be leveraged as part of a country's DPI. Financial sustainability is relevant both to the continued viability of individual software products that ultimately comprise a country's DPI as well as the on-going operational cost of managing and maintaining the set of software systems that make up DPI as a whole. Given that many products deployed as DPI pilots or early-stage investments start with philanthropic or other grant funding, understanding upfront deployment costs and ongoing operating expenses is key to identifying financial sustainability models that can support implementation at scale. Without early consideration, countries that are early adopters of these products may face significant disruption when financial support waivers. Many prominent DPGs used for foundational DPI (e.g., MOSIP and Mojaloop) and DPGs widely used in specific sectors (such as DHIS2 in the health sector) have relied on donor funding for initial development and growth. Developing and evolving financial sustainability strategies will be key to their ability to continue to function as robust and secure products that can be implemented as part of a country's DPI.

Illustrative Cost Drivers

Start-up costs affected by:

- Maturity of underlying technology infrastructure
- Availability of foundational DPI system
- Complexity of use case
- Alignment of public and private stakeholders around goal
- Local technical capacity
- Scope

Ongoing operating costs for DPGs implemented as building blocks:

- Core development
- Maintenance
- Hosting
- Security
- Community support
- Training

As an additional challenges for the agriculture sector, the need to create financially sustainable services may create a dynamic where ecosystem actors make services and products that benefit larger value-chain actors initially[42], rather than prioritizing those that benefit SSPs, who have less ability to pay for services. Creating financially viable business models for DPI-enabled services like AI-based advisory are key challenges, as costs of hosting and running models are likely new expenses for many organizations. This may create more interest in creating small language models as a sector-specific building block that could defray individual innovators' costs of model training and inference.

From a country standpoint, implementing a particular DPG at scale as a foundational building block for DPI or a sector-specific building block can have significant financial implications. Despite their licenses being free, rolling out and maintaining a national scale DPG can cost hundreds of thousands of US dollars to millions, depending on the number of users, maturity of the underlying digital ecosystem, and capacity of local workforce to maintain and support open-source tools. It is helpful to consider the total cost of ownership (TCO) of DPGs when planning for DPI rollout in the agriculture sector. Resources are available from the World Bank (for identification systems) as well as for individual DPG-owners supporting implementation of one DPG as a component within a broader national digital public infrastructure.

Proposed approaches:

- For all, consider business model viability from the start, exploring combinations of public support, private-sector partnerships, fee-for-service models from product owners, or philanthropic investment to support the roll out and maintenance of DPGs implemented as sector-specific building blocks.
- For start-ups or new products seeking wide adoption as a DPG, consider potential barriers and success factors to sustaining a high-quality product and ensuring long-term viability. Many such factors are documented in Business Models and Key Success Drivers of Agtech Start-Ups.
- For software products that serve a building block function, many potential revenue models may be viable. Digital Square recently produced an overview of revenue models for health-related DPGs. Those business models are relevant to software DPGs in all sectors.
- For country governments and individual product owners, develop total-cost-of-ownership analyses to inform DPI implementation roadmaps.
- For the donor community, it would be useful to develop and pilot several business models and provide transparency on long-term donor funding plans.

Building an Evidence Base for impact: Monitoring & Evaluation

As DPI is an emerging approach, multiple questions about its measurement remain, both in terms of prevalence and the ultimate impact for individuals, governments, private sector actors, and innovators. While there are pieces of evidence regarding benefits of specific foundational DPI systems,[43] these are not always measured against a bespoke version of the service (e.g., digital payments implemented as DPI versus digital payments in a bespoke implementation). There are also questions with respect to consistently measuring both the prevalence of systems that constitute DPI and the impact of DPI-enabled systems and services. Most implementations utilizing foundational DPI or sector-specific building blocks in the agriculture sector do not have a set of indicators in place to measure contributions to an evidence base.

Without systematic measurement approaches, it will be difficult to show that DPI is achieving the envisioned transformative impact, whether the impact it does create is positive and equitably distributed across stakeholder groups in the ecosystem, and whether the benefits outweigh the costs. Given that anticipated benefits of DPI and DPI-enabled services include broad participation and improved access to services, countries will need frameworks and processes to measure not only short-term outputs like reduced fragmentation but also longer-term and macroeconomic impacts. Further, given how many implementation contexts there will be, there is a risk of introducing fragmentation in how DPI and its impacts are measured, hindering the ability to create a robust, consistent evidence base. Gates Foundation, Co-Develop, the Digital Impact Alliance (DIAL), the Abdul Latif Jameel Poverty Action Lab (J-PAL), and University College London (UCL) have all taken steps to address these challenges as they relate to foundational DPI. See Section 10 for further information.

For the agriculture sector, this work will continue to be relevant as the use cases that leverage foundational DPI would be considered DPI-enabled services that could contribute to a larger evaluation effort. At the same time, it will be important for the agriculture community to identify the key outcomes it expects the implementation of DPI and DPI-enabled services to produce and align on common indicators.

Proposed approaches:

- Align on a definition of DPI and DPI-enabled services in coordination with global stakeholders to facilitate consistent and comparable measurement of their prevalence.
- Develop measuring and evaluation (M&E) frameworks with clear outcome metrics for DPI-enabled services in the agriculture sector. Engage academia, agriculture research firms, and farmer collectives to create a common, feasible set of measures that show impact for SSPs.
- Include consideration for indicators or metrics that have aspects of gender equity and a focus on realized outcomes, such as market participation, access to inputs, or improved yields.

Avoiding Exclusion

Exclusion can manifest many ways in an ecosystem, from reliance on established systems and databases that may include biased or incomplete data, to using technology that excludes people otherwise included in those systems.

With linkages between foundational DPI and sector-specific building blocks like farmer registries, exclusion is a concern when registration is required for receipt of critical benefits (e.g., payments and identity systems to deliver an agriculture subsidy).

Exclusion may also result from use of underlying data sets that embed pre-existing exclusions, for example, relying on incomplete land registries to establish a farmer ID. During AgriStack's implementation in India, linking Aadhaar number to land records raised concerns about exclusion[44] because of incomplete and sometimes inaccurate land registries at the village level. AgriStack also faced concerns[45] for the implications for tenant farmers, who do not own the land they farm and thus might be excluded if inclusion in a land registry was a prerequisite. Further, while there are some data protections outlined in India's data protection bill, they largely would not cover farm data that is not inherently "personal" but that farmers would like to have discretion over, whether and how its shared.

Exclusion might result from a failure of a software product responsible for facilitating access, e.g., farmer registries that fail to identify eligible individuals or make errors in authenticating the identity of individuals for subsidies or services to which they are entitled. Alternatively, exclusion might result from existing digital literacy, income, or social divides that limit participation in any service that requires engagement in a digital system (e.g., failure of access, limited availability or affordability of digital devices and connectivity associated with registration, lack of digital skills needed to support engagement with registration process, or low literacy levels).

Proposed approaches:

- Ensure there are alternative offline processes through which benefits can be delivered in the case of failure and maintain a system for grievance and redress to ensure errors can be communicated, particularly if the system is used to deliver a critical benefit.
- Choose relatively mature, robust products to achieve the desired functionality to minimize system failures or errors when selecting software products to implement identification and registration.
- Invest in complementary, cross-sectoral initiatives to strengthen skills and familiarity with digital tools where engagement with digital systems is needed. These can include digital literacy campaigns, user feedback sessions to understand barriers, and common civic service centers to support SSPs with low digital skills.
- Build trust through community networks such as community leaders or collectives.
- Include a focus on inclusion in the approach to designing and monitoring DPI-enabled services, particularly where they confer an essential benefit to farmers.

Protecting Privacy of SSP Data, Unauthorized Use of Data Held in DPI Systems

Data breach and misuse is relevant to foundational DPI utilized in the agriculture sector, as well as sector-specific building blocks that store and utilize personal and potentially sensitive data, e.g., personal details and contract history data that may be included in farmer registries. Beyond individual harm that may occur from unauthorized use, repeated breaches in public systems over time can erode public trust in DPI systems and discourage individuals and businesses from participating in DPI ecosystems. This is particularly important in sectors where many people from low-income households are engaged and might be more vulnerable to data breaches or scams.

Many of the countries in the case studies above have or are developing data privacy legislation and relevant data sharing frameworks, and these can affect data exchange initiatives. In Kenya for example, KALRO's efforts to establish data sharing partnerships with various ministries has faced delays. Lengthy partnership negotiations can often take place with each individual actor, even between government ministries.

In some countries seeking agriculture building blocks, national data protection frameworks may be absent. This was the case in Lao PDR, where stakeholders looked to regional data protections endorsed by the Association of Southeast Asian Nations (ASEAN) and similar frameworks such as the European Union's General Data Protection Framework to determine reasonable protections. Further, appropriate data governance and data protections for use cases that require sharing personal data for AI models is an emerging area where formal frameworks are often not yet adopted. Implementers may need to proactively and collaboratively determine appropriate safeguards from emerging global guidelines.

Proposed approaches:

- Coordinate roll out of DPI building blocks with the implementation of national data protection frameworks and institutional capacity to implement and ensure compliance with data protection and cybersecurity practices.
- Adopt clear data governance frameworks that address public and private stakeholder concerns around data ownership, consent-based use, and use of data for AI and other data-driven innovations. Where no national frameworks exist, consider relevant regional or international frameworks. Several options for guidance on data governance for AI, including recent work from the Open Data Institute. Additionally, the Organization for Economic Cooperation and Development (OECD) published a catalogue of tools from the OECD.ai Policy Observatory as well as specific considerations around data governance for agriculture.
- Engage stakeholders who will be part of data sharing agreements around a mutually valued use-case to facilitate buy-in to the process and commitment to following through on necessary agreements.
- Explore decentralized architectures that enable data sharing without centralization of data to lower consequences of data breach where possible.
- Invest in securing products and systems used as part of DPI, including appropriate cybersecurity standards and monitoring capacity.

Summary

As more countries take steps to implement a DPI approach in agriculture, investing in ecosystem strengthening will become critical to its success. Addressing each of the dimensions above will be a long-term project requiring participation of funders, governments, private sector actors, technology implementers, and individuals from across the agriculture value chain.

SECTION 09
How to Get Started

Key Messages

1. Countries will take unique pathways to building DPI systems and complementary, sector-specific building blocks.

2. Important guiding factors include building off what already exists, identifying specific use cases and concrete outcomes to be able to show early successes, and considering benchmarks or key performance indicators that incentivize use and reuse of components across use cases.

Based on the considerations above, stakeholders ready to start implementing a DPI approach can begin with the following approaches. In many cases, successful implementations are government-led yet work in collaboration with a range of stakeholders supporting funding, technical implementation, and relevant coordination support, as discussed further below.

Determine the Value-Proposition for the Dpi Approach for Agriculture in Context

Before investing in the DPI approach for agriculture, it is essential to clearly articulate the rationale for doing so. While formal return on investment (ROI) assessment may not be feasible before initial investment, stakeholders should still have a clear sense of problems to be addressed and an estimate of expected results. In the long term, policymakers, donors, and implementers should take steps to enable an ROI assessment to determine whether a DPI approach is the most effective and sustainable way to address the specific challenges in the current system. This includes analyzing the full cost of building, operating, and governing DPI over the short, medium, and long term; identifying when and for whom the returns are likely to materialize; and determining whether the expected benefits outweigh the costs.

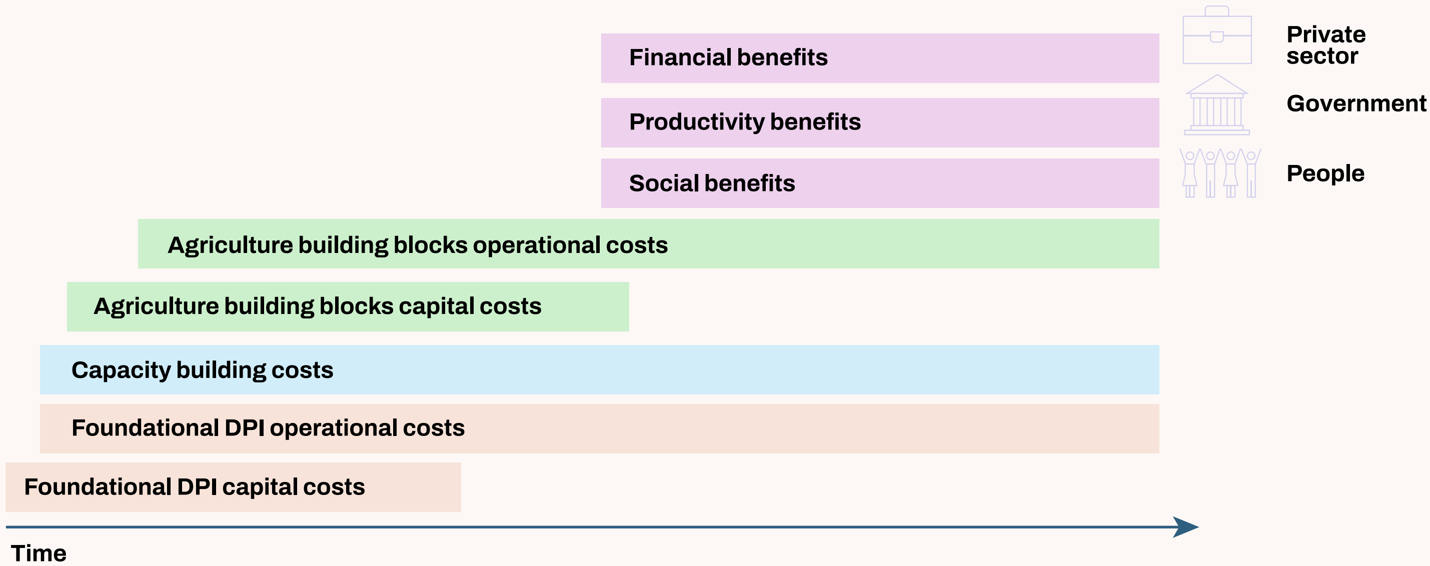
As discussed earlier, DPI is not an end in itself – it is a foundational enabler designed to support a more integrated and interoperable digital ecosystem. However, it may not be the most appropriate solution for all pressing problems. In some cases, more targeted digital or analog interventions may be required. A careful diagnosis of needs and an assessment of whether DPI offers a comparative advantage is essential to ensure that investments in DPI are fit-for-purpose and deliver public value at scale.

The Return on Investment of the DPI Approach for Agriculture

Investing in DPI for agriculture holds the potential for significant benefit yet also comes with substantial costs. Determining ROI for DPI requires detailed cost and impact estimates. However, because the DPI approach is relatively new, there is limited evidence on the impact of DPI, let alone the impact of DPI in the agriculture sector. Similarly, there remains limited availability of cost estimates to inform such an analysis. In the absence of robust, comparable estimates, stakeholders can consider a theoretical framework for determining the ROI of the DPI approach in agriculture, highlighting available data where possible.

Figure 9 presents the potential benefits and costs that would likely be relevant for an ROI analysis for DPI for agriculture. The actual ROI will, of course, depend on several contextual factors, including a country's digital maturity (e.g., level of digitization and infrastructure), priority use cases (e.g., digital advisories vs. subsidy delivery), demographic and economic characteristics (e.g., share of the population employed in agriculture, income levels, digital literacy), success of implementation (e.g., farmer adoption and usage), strength of the private sector ecosystem, and the quality of investments in capacity-building and inclusion.

Figure 9 Potential Types of Benefits and Costs to be Considered for DPI for Agriculture Investments



Benefits include financial, productivity, and social benefits, which can accrue to people, government, or private sector enterprises. Importantly, these benefits are highly dependent on the ecosystem in which they are implemented, including their analog counterparts. For example, while Aadhaar and UPI facilitated financial inclusion in India, the Government of India's financial inclusion program, Pradhan Mantri Jan Dhan Yojana (PMJDY), was instrumental.

Financial benefits: DPI could enable cost savings for governments, farmers, and the private sector in the agriculture sector. For example, the DPI approach could reduce administrative costs on the delivery of government agriculture subsidies, and reduce the cost of accessing credit, insurance, and subsidies for farmers. Existing evidence which is not specific to the agriculture sector highlights this. For example, in India, leakages dropped by 41%[46] in employment and pension social programs after introducing biometric-based digital payments. In Mexico, centralizing and digitizing G2P payments led to an estimated 3.3% annual savings[47] on G2P payments. In Philippines, switching to digital identity verification helped a bank reduce costs by 86%[48]. In Mozambique, beneficiaries saved over 30 minutes[49] per transfer when the modality switched from cash to mobile money payments.

Similarly, in the agriculture sector, India's switch to direct bank transfer system for fertilizer subsidies helped save ~US $2.2 billion[50] (INR 18,700 crore).

Productivity benefits: DPI-enabled services can increase agricultural productivity by improving yields and input efficiency. Farmers can receive tailored advice (e.g., on optimal sowing time, input use) and better information (weather, soil data) to avoid losses and boost output. For example, In Zambia,[51] a digital choice-based model incentivized payment service provider participation leading to higher competition, lower market prices, service closer to rural communities, and products catered to bottom of the pyramid. In Telangana, India,[52] a large-scale digital farming initiative (using AI chatbots, soil sensors, and data platforms) saw

21% higher crop yield for chili farmers, a 9% drop in pesticide use, and 5% lower fertilizer use, while improving crop quality. These productivity gains often convert directly into financial benefits but are considered separately to highlight efficiency improvements in food production.

Social benefits: This component captures the non-financial or indirect benefits of DPI – primarily improved inclusion, access, and equity in the agricultural economy. DPI in agriculture can help democratize the benefits of digital systems. This has precedent; India's foundational DPI helped more than doubled bank account ownership of adults and narrowed the gender gap in financial access[53] from 20 percentage points to nearly 0 in a decade. Similarly, in Pakistan, digital ID-linked cash transfer increased women's reported control[54] over cash by 9 percentage points, and in Niger, digital payments led to greater decision-making power[55] of women and increased the diet diversity[56] of their household up to 16%. In agriculture, DPI can similarly narrow the "digital divide." Benefits could include more equitable service delivery with small farmers receiving timely payments and subsidies directly, women farmers gaining access to credit and markets, improved transparency, and community-level outcomes like reduced poverty and rural development.

Cost Considerations

Realizing these benefits of the DPI approach will likely require high upfront public investment and continued operation costs, with returns often accruing over the medium and long-term. For example, as previously discussed, in India digital ID-based authentication was free of charge until December 2019 and fast payment systems were zero-cost for basic peer-to-peer and merchant transactions while the government spent over US $130 million (INR 1148 crore) on marketing and incentives while the government spent over US $130 million (INR 1148 crore) on marketing and incentives[57]. Similarly, India's Digital Agriculture Mission was allocated US $340 million[58] (INR 2,817 crore) for establishing core infrastructure and registries, with an additional US $720 million[59] (INR 6,000 crore) in special central assistance to states. Investments in DPI have primarily been public and subsidized, reflecting the DPI approach's nature as a public good, though private costs also emerge through integration, app development, and user engagement, particularly among AgriTech firms and financial service providers that build atop DPI layers.

Importantly, the benefits of DPI will likely accrue over the medium to long term, while costs are front-loaded. ROI might emerge over 5-10 years as systems mature, trust is built, use-cases evolve, and adoption deepens. Additionally, foundational platforms often enable unexpected value creation over time. For example, when India's national ID was first introduced, few anticipated its role in enhancing market linkages, crop insurance, or land record digitization. This makes it more difficult to conduct ROI analyses to account not only for static payback timelines but also for the dynamic, evolving nature of DPI-enabled use-cases in the long-run.

Find Like-Minded Champions Committed to Dpi Approach

Investing in DPI and taking the approach to sectors is a long-term action, and political will is essential to the process, as is the development of a governance approach characteristic of DPI. Start with a champion and find partners who will be supportive. Articulate the value proposition for the local context and socialize with key ministries, funders, or members of DPG or DPI communities (many are highlighted in the following section and linked below, as relevant).

Take Stock Of Existing In-Country Data Systems and Assets, as well as Potential Collaborators

An assessment of the agricultural sector digital environment is essential to inform the strategy, including an understanding of what data assets and systems have already been created that can contribute to key building blocks like registries and data services. If only static databases exist, consider what it would take to build connections and open up for reuse. Investment in DPI can mean strengthening and enhancing the interoperability of existing assets, instead of necessarily building from scratch.

Similarly, identifying potential collaborators working in similar or complementary parts of the value chain can create opportunities to share knowledge, experience, and resources that can strengthen the proposed implementation.

Sequence and Prioritize

It is important for countries to identify their starting point and develop a phased implementation roadmap, starting with basic use cases and scaling to more integrated solutions. For instance, low-maturity contexts could begin with a narrow focus: establishing one or two foundational DPI elements (e.g., digital ID or payment rails) and linking them to a single impactful agricultural use-case or capability (e.g., e-vouchers or digital advisory). More digitally advanced countries may layer interoperable registries, data-sharing protocols, and open networks to support more complex services such as bundled insurance-credit products or integrated supply chains. Highlighting quick wins based on the starting point will show tangible results, build confidence, and enable learning.

Identify 1-2 High Level Use Cases That are Mutually Valued and Could be Enabled With Dpi and Sector-Specific Building Blocks

Starting with a high-value use case provides focus and offers a clear reason for ecosystem stakeholders to engage with DPI-enabled services, creating value quickly. In India, an early use case was subsidy distribution. In contexts where public benefit programs are not as large, like Lao PDR, the first use cases relate to targeted management and monitoring. Consider use cases that integrate services by utilizing multiple DPI components, for example advisory services that can also facilitate purchasing of relevant inputs through an open network. For additional examples, see *DPI Exemplar Stories*.

Identify Dpgs That Could Meet Needs for Digital Building Blocks

While building blocks do not necessarily need to be registered DPGs, using products that are designed for interoperability, open-source, and have strong documentation and communities behind them can offer a number of advantages. Countries may find it easier to get started, where possible, by adapting and configuring DPGs such as those listed in Appendix 2 rather than trying to build with proprietary products. When considering what products and software to use, consider the maturity of the product, quality of technical assistance and roll-out support available, operating costs to maintain and manage, and interoperability with any existing DPI already in place in the country.

Focus on the User-Experience

Digital tools are only meaningful if they address real user needs. Farmers, input suppliers, buyers, and others in the agricultural ecosystem must find the solutions intuitive, useful, and trustworthy. Implementers should prioritize user-centric design, actively solicit feedback, and build trust through transparency and responsiveness. Measurement of user satisfaction and outcomes, especially for marginalized groups, should be embedded in project design and used to guide course corrections. This is key to adaptation and success in the long-term.

Pay Attention to Enabling Factors

Engage diverse stakeholders to understand where non-technology investments may be needed. These might include consideration for:

Policy adoption
For example, advocating for financing institutions to use DPI-enabled r identification and eKYC to encourage digital lending services to SSPs.

Data governance
For example, engaging civil society groups working on data protection, data ethics, and fair use of data to inform approaches on using farmer data and developing shared data services for the sector.

Market shaping
For example, encouraging participation in open market networks by offering a minimum price guarantee for goods sold over the network.

Technical standards development
For example, engagement with regulatory bodies and development communities to encourage use of common standards that ease compliance and certification.

Financial sustainability and business models for use
For example, considering a nominal fee scale for stakeholders to access core data services to ensure revenue to continue to curate, clean, and maintain API-accessible data.

With a full understanding of the technology and ecosystem development investment that may be needed, develop a costed plan and activities for an initial funding timeframe.

Consider how Existing Networks and Physical Infrastructure can Complement Extend Reach of DPI-Enabled Services

Consider how existing infrastructure such as postal networks, rural extension services, and local cooperatives can be leveraged for outreach, training, and deployment of DPI-enabled solutions. These trusted networks can play a vital role in bridging the last-mile gap and ensuring digital solutions reach the communities that need them most.

Secure Funding Partners That will Support Implementation Long Enough to Show Value

Approach funders interested in supporting a DPI approach. There is a growing coalition of development funders and technical assistance groups ready to support countries in these efforts.

Pilot

Begin pilot implementation in a conducive context. This could be at a sub-national or national level, with consideration for political willingness of government and value chain stakeholders, underlying digital maturity, alignment with local needs and capacity. Pilots allow implementers to gain an additional level of learning and insight into how systems actually work in context, which can inform refinements in design, architecture, and necessary supporting investments before scaling. The World Bank and other partners are already supporting countries in piloting various implementations and use-cases.

Expect Progress to Take Time and Monitor Outputs and Outcomes

Achieving fully DPI-enabled ecosystems is a long-term goal. Consider what reasonable outputs and outcomes are expected in the initial years. Given the importance of building for reuse, consider mechanisms to keep track of use by other implementers, integration into complementary services, and adaptation that may be made from outside the sector. The World Bank and other partners continue to support monitoring and evaluation efforts to evaluate and measure the impacts of DPI.

SECTION 10

Relevant Resources and Ongoing Initiatives

Key Messages

1. There are wide range of existing communities and initiatives involved in supporting a DPI approach in agriculture.

2. Opportunities to engage include product development, implementer communities of practice, and multi-country dialogues for shared learning and collaboration.

The digital agriculture community is taking steps to strengthen its collective capacity to put a DPI-approach into action. From communities working on DPGs for the agriculture sector to working groups on standards development and measurement, there are multiple efforts open for interested implementers to engage and shape the future of digital agriculture. Coalitions and initiatives are grouped by topic below.

Digital Public Goods for Agriculture

DPGA: The global community creates resources and shares knowledge on the benefits of adopting a DPI approach. The Digital Public Goods Alliance (DPGA) keeps a registry of DPG products that may be suitable for implementation in the agriculture sector, a resource of open-source building blocks that can complement foundational DPI and reduce fragmentation within the sector.

TAC: The Agri Collaboratory (TAC) is a group working on DPGs for agriculture that can serve as building blocks that highlights use cases around finance for small-scale producers and reducing post-harvest waste. TAC is also driving the creation of an Agri Digitalization Framework and indices in the Global South.

OAN: OpenAgriNet (OAN) is packaging several use cases, including its open network protocol and AI layer, as DPG toolkits for integrating its infrastructure into national agricultural strategies f governments in India and Africa.

Refer to Appendix 2 for examples of existing DPGs and building blocks used to support agriculture.

Standards Development and Adoption for the Agriculture Sector

Traceability: Digital Integration of Agricultural Supply Chains Alliance (DIASCA) is an initiative of the German Corporation for International Cooperation (GIZ) with an aim to develop common open standards for traceability. Their technical working paper, Realizing the Potential of Interoperability for Building More Trustworthy and Transparent Global Agrifood Supply Chains, outlines a potential approach to interoperable traceability systems for agriculture. The DIASCA network has a dedicated Working Group on Traceability and Governance that meets regularly to discuss interoperable supply chain systems.

Farmer Registries and Social Protection: The Digital Convergence Initiative (DCI) promotes interoperability for social protection systems and has Standards Drafting Groups to create standards documentation for process, data, and API. Standards Committees review draft standards in coordination with the Standards Drafting Groups. Standards for interoperability between Farmer Registries and Social Protection Systems are under development.

The European Data Spaces initiative offers a model for sectoral data sharing that prioritizes interoperability, competition, and data protection. Its federated architecture and strong safeguards are relevant to emerging agricultural data ecosystems and can inform the design of secure, consent-based agriculture building blocks.

DPI Monitoring and Evaluation Initiatives

There are multiple ongoing efforts to build an evidence base demonstrating the impact of DPI. The UCL Institute for Innovation and Public Purpose's DPI Map project has launched a Community of Practice (CoP) for DPI Measurement to coordinate stakeholder efforts on monitoring and evaluating DPI programs. The DPI Measurement CoP aims to share knowledge across the community, provide a forum for the discussion of research questions and measurement frameworks, and support related governance efforts (e.g., Universal DPI Safeguards Working Group). Participation in the CoP is open to interested stakeholders, including researchers, implementers, and government actors. Recent and upcoming CoP meeting topics include measurement approaches, inclusion, interoperability, and adoption.

The Digital Impact Alliance (DIAL) is working on developing a common reference framework for the measurement of DPI. The framework is focused on core DPI and does not currently include monitoring sector-specific DPI. A key step in creating the framework is identifying DPI and its attributes. The framework will ultimately outline input and evaluation metrics and outcome and impact metrics. Input and evaluation metrics include components on access, end-user experience, accountability, and sustainability. Outcome and impact metrics focus on people, households, government, and markets. DIAL has also identified recommendations for DPI impact measurement systems, with a focus on digital payments; these learnings can be applied to the DPI-enabled agri-finance use cases.

The Oxford's Digital Public Infrastructure Research Lab is a new initiative working to provide evidence of the impact of DPI, with a particular focus on inclusion in LMICs. The foremost focus of the lab's research is digital ID in Ethiopia (Fayda system) through a research platform (Fayda.Lab) in coordination with the Government of Ethiopia, the World Bank, and Development Impact Group (DIME). Fayda.Lab will collaborate with the Government of Ethiopia's National ID Authority (NIDP) to support DPI implementation.

World Bank's Identification for Development (ID4D) Initiative as well as J-PAL Africa's Digital Identification and Finance Initiative work with governments, the private sector, and donors to build the evidence base on the impacts of DPI.

National Dialogues and Planning for National Agriculture Data Infrastructure

The Commonwealth Secretariat is the seat for 56 member countries with an estimated population of 2.7 billion people spread across the five regions of Asia, Africa, Europe, the Caribbean and Americas, and the Pacific. For the past 2-3 years, the Digital Agriculture workstream under the Commonwealth Connectivity Agenda for Trade and Investment program has been exploring a model of DPI approach in agriculture, the National Agricultural Data Infrastructure (NAgDI), that could enable interoperability between multiples data systems at country level. NAgDI is about fostering an enabling environment in countries for secure, decentralized, interoperable, and financially sustainable data exchange mechanism through policies and an independent governance model. A guide for investing in NAgDI (to be published in the second half of 2025), has been collaboratively developed with experts from member countries, including through regional and national dialogues on agriculture data management. The guide provides a comprehensive overview of a sectoral approach to DPI aimed at establishing a coordinated and collaborative framework for agricultural data management across Commonwealth countries and beyond.

Foundational DPI

The World Bank DPI Initiative, consists of ID4D, G2Px, and Fast Payments initiatives to help countries realize the transformational potential of inclusive and trusted identification systems, digital government to person payments, and fast payment systems to improve service delivery across sectors.

50-in-5 Campaign

Founded in 2023, the 50-in-5 campaign is a country-led advocacy initiative aiming to support 50 countries in the design, launch, and scale of DPI components by 2028. Its partners include the Gates Foundation, Centre for Digital Public Infrastructure, Co-Develop, the Digital Public Goods Alliance, and the United Nations Development Programme (UNDP), and it is supported by GovStack, the Inter-American Development Bank, and UNICEF. The campaign has 11 “First Mover” countries doing flagship work on foundational DPI, including: Bangladesh, Estonia, Ethiopia, Guatemala, Moldova, Norway, Senegal, Sierra Leone, Singapore, Sri Lanka, and Togo.

Conclusion

Addressing data fragmentation in the agriculture sector is critical to unlocking the full potential of digital transformation for agricultural ecosystems. Without it, the sector risks perpetuating continued data fragmentation and data gaps that infuse uncertainty across the value chain. Uncertainty about farmers, yields, and product provenance lowers supply-side willingness to lend, guarantee prices, and competitively sell products. It hinders the ability of SSPs to access credit for inputs, receive productive advisory services to improve yields, and gain access to markets to achieve competitive prices. Yet DPI offers an alternative. By adopting a DPI approach, stakeholders can move beyond fragmentation to establish foundational systems and complementary building blocks that unlock these challenges. As countries increasingly invest in foundational DPI components like digital identity, fast payment, and sector-agnostic data exchange, the opportunities for DPI to enable sector-specific use case solutions like farmer profiles, agri-finance, product traceability, and personalized advisory for every farmer will only become more achievable. The strategies and resources outlined in this document provide a clear starting point for stakeholders ready to champion this approach. With a growing coalition of stakeholders aligned around the vision for what DPI can achieve, there is strong potential for agri-food systems to achieve highly participatory, competitive markets that meet the demands of a changing world – today and in the future.

Appendix 1: Definitions of DPI Across the Global Development Community

Organization	Definition
Universal DPI Safeguards Framework, informed by G20 Definition (2023)	A set of shared digital systems that should be secure and interoperable, and can be built on open standards and specifications to deliver and provide equitable access to public and / or private services at societal scale and are governed by applicable legal frameworks and enabling rules to drive development, inclusion, innovation, trust, and competition and respect human rights and fundamental freedoms
UNDP DPI Playbook	DPI creates exponential societal outcomes within and across sectors. It is composed of open, interoperable technology with transparent, accountable, and participatory governance frameworks to unlock innovation and value at scale.
Co-Develop	Society-wide, digital capabilities that are essential to participation in society and markets as a citizen, entrepreneur, and consumer in a digital era. Because it is essential, DPI should be guaranteed by public institutions to be 1) inclusive, 2) foundational, 3) interoperable, and 4) publicly accountable, as it is deployed in countries around the world.
Center for Digital Public Infrastructure (CDPI)	A set of technology building blocks powered by interoperable open standards/ specifications operated under a set of enabling rules with open, transparent, and participatory governance to drive innovation, inclusion, and competition at scale.
World Bank	Systems that serve as foundational, digital building blocks for public benefit.

Appendix 2: Selected Products and DPGs to Consider as Building Blocks for the Agriculture Sector

Product	Primary Functionality	Owner/Host	Description[72]	DPG Registry Link
AgStack Toolbox	Multiple	Linux Foundation	Open repository of free, reusable software tools, frameworks, and models used by global agriculture stakeholders, including tools for interoperable traceability and Asset Registry	*n/a (as of August 2025)*
OpenSPP	Registry	Association for Digital Cooperation	"OpenSPP is an integrated and digital social protection information system that enables governments and humanitarian agencies to streamline the creation and management of assistance programs."*	DPGA Registry
Sunbird RC	Registry	EkStep Foundation	"'Sunbird Registry and Credential' or simply 'Sunbird RC' is an open source software to rapidly build and deploy next generation electronic registries and verifiable credentials including attestation and verification flows."*	DPGA Registry
AgriJSON	Data standard	Centre for the Fourth Industrial Revolution/World Economic Forum (C4IR/WEF)	Standard data schema for defining the semantics of agricultural data to support data exchange.	n/a (as of August 2025)
INATrace	Standards-based traceability	GIZ	Open-source solution providing transparency in the global agriculture supply chain through end-to-end traceability, with a focus on SSPs.	n/a (as of August 2025)
FarmStack	Data exchange	Digital Green	Open source product suite which enables the secure transfer of data across the agricultural ecosystem.*	DPGA Registry
AGROVOC	Terminology	FAO	"AGROVOC is a thesaurus of 41,000+ agricultural concepts and relationships in up to 42 languages, available for public use to facilitate access and interoperability of data across institutions and languages."*	DPGA Registry

OpenAgriNet	Discovery network and AI Layers	Center for Open Societal Systems (COSS), EkStep, Foundation for Interoperability in the Digital Economy (FIDE)	OAN is in the process of packaging a set of DPGs to support the open network solution for agriculture. OAN-developed DPGs support use cases including: real-time agricultural information, AI-powered advisory services, and training and discovery tools.	n/a (as of August 2025)
AGRIS Open Data Set	Core data set	FAO	"The AGRIS Open Data Set is the Open Data serialization of a big subset of the AGRIS database, one of the most comprehensive catalogs of food and agricultural scientific literature providing free access to more than 13,000,000 bibliographic records in more than 100 languages."*	DPGA Registry
FAO Agricultural Stress Index System	Core data set	FAO	"The Agricultural Stress Index System (ASIS) monitors agricultural areas with a high likelihood of water stress/drought at global, regional and country level, using satellite technology."*	DPGA Registry

References

[1] International Labor Organization. Sector Portal: Agriculture; Plantations; Other Rural Sectors. https://www.ilo.org/topics-and-sectors/industries-and-sectors/agriculture-plantations-other-rural-sectors

[2] United Nations. (11 October 2023). Extreme Poverty in Developing Countries Inextricably Linked to Global Food Insecurity Crisis, Senior Officials Tell Second Committee. Meetings Coverage and Press Releases. https://press.un.org/en/2023/gaef3590.doc.htm#:~:text=Agriculture%2C%20being%20the%20most%20important,families%20in%20the%20agriculture%20sector%E2%80%9D

[3] The Global Goals. (n.d.). The Global Goals. https://globalgoals.org/goals/

[4] Keith Fuglie, Stephen Morgan, and Jeremy Jelliffe (30 September 2024). Global Changes in Agricultural Production, Productivity, and Resource Use Over Six Decades. Retrieved from Amber Waves. Economic Research Service, United States Department of Agriculture. https://www.ers.usda.gov/amber-waves/2024/september/global-changes-in-agricultural-production-productivity-and-resource-use-over-six-decades

[5] Tim G. Benton and Rob Bailey. (29 April 2019). The Paradox of Productivity: Agricultural Productivity Promotes Food System Inefficiency. Cambridge University Press. https://www.cambridge.org/core/journals/global-sustainability/article/paradox-of-productivity-agricultural-productivity-promotes-food-system-inefficiency/4D5924AF2AD829EC1719F52B73529CE4

[6] United Nations. (n.d.). Global Issues. https://www.un.org/en/global-issues/population

[7] Food and Agriculture Organization of the United Nations. (2024). The State of Food Security and Nutrition in the World 2024: Financing to End Hunger, Food Insecurity and Malnutrition in All Its Forms. https://openknowledge.fao.org/handle/20.500.14283/cd1254en

[8] Beanstalk AgTech. (2023). State of the Digital Agriculture Sector: Harnessing the Potential of Digital for Impact Across Agricultural Value Chains in Low- and Middle-Income Countries. https://static1.squarespace.com/static/61f723d2d47f140c4200a1d9/t/65557be9c2f23404d1576704/1700101355494/State+of+the+Digital+Agriculture+Sector+in+LMICS+-+Whole+Report.pdf

[9] GovStack. (May 2022). GovStack Definitions: Understanding the Relationship between Digital Public Infrastructure, Building Blocks & Digital Public Goods. https://www.digitalpublicgoods.net/DPI-DPG-BB-Definitions.pdf

[10] World Bank Group. (March 2025). Digital Public Infrastructure and Development: A World Bank Group Approach. https://openknowledge.worldbank.org/entities/publication/cca2963e-27bf-4dbb-aa5a-24a0ffc92ed9

[11] Karthik Muralidharan, Paul Niehaus, and Sandip Sukhtankar. (2022). Integrating Biometric Authentication in India's Welfare Programs: Lessons from a Decade of Reforms. India Policy Forum, National Council of Applied Economic Research 18(1), 139-172. https://www.ncaer.org/wp-content/uploads/2022/09/IPF2021Paper4.pdf

[12] Institute for Innovation and Public Purpose, University College London (October 2024). The Digital Public Infrastructure Map. https://dpimap.org/

[13] PIB Delhi. (21 April 2025). India's DBT: Boosting Welfare Efficiency: Report Reveals ₹3.48 Lakh Crore in Savings and 16-Fold Increase in Beneficiaries. Ministry of Finance, India. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2123192&utm

[14] ibid.

[15] ibid.

[16] ibid.

[17] MicroSave Consulting. (19 May 2025). An Integrated Digital Platform That Simplifies Vital Agricultural Services for Indian Farmers. Signature Projects. https://www.microsave.net/signature_projects/an-integrated-digital-platform-that-simplifying-critical-agricultural-services-for-indian-farmers/

[18] Ritul Gaur and Mansi Kedia. (24 April 2025). Making DPI Sustainable. The Indian Express. https://indianexpress.com/article/opinion/columns/making-dpi-sustainable-9961880/

[19] ibid.

[20] PIB Delhi. (1 April 2025). Digital Identities to Farmers. Ministry of Agriculture & Farmers Welfare. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2117390&utm_source=chatgpt.com

[21] PIB Delhi. (13 June 2025). National Conference on Agri Stack: Turning Data into Delivery. Ministry of Agriculture & Farmers Welfare. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2136255&utm_source=chatgpt.com

[22] Xavier Giné, Jessica Goldberg, and Dean Yang. (October 2012). Credit Market Consequences of Improved Personal Identification: Field Experimental Evidence from Malawi. American Economic Review 102(6), 2923-54. https://www.aeaweb.org/articles?id=10.1257/aer.102.6.2923

[23] Karthik Muralidharan, Paul Niehaus, and Sandip Sukhtankar. (2022). Integrating Biometric Authentication in India's Welfare Programs: Lessons from a Decade of Reforms. India Policy Forum, National Council of Applied Economic Research 18(1), 139-172. https://www.ncaer.org/wp-content/uploads/2022/09/IPF2021Paper4.pdf

[24] Julia Clark and Georgina Marin. (12 September 2023). Why This Matters: Evidence Building on DPI. World Bank. https://thedocs.worldbank.org/en/doc/8325e21eaf7ab04cd8a8eede4d5e06da-0050112023/original/DPI-Workshop-Why-this-matters-Julia-Clark-Georgina-Marin.pdf

[25] ibid.

[26] Identification for Development, World Bank. (March 2022). Using Biometrics to Deliver Cash Payments to Women: Early Results from an Impact Evaluation in Pakistan. https://documents1.worldbank.org/curated/en/099155004142238180/pdf/P1763410d1e1af00108e170e5754d04fed9.pdf

[27] Jenny C. Aker, Rachid Boumnijel, Amanda McClelland, and Niall Tierney. (October 2016). Payment Mechanisms and Antipoverty Programs: Evidence from a Mobile Money Cash Transfer Experiment in Niger. Economic Development and Cultural Change 65(1). doi: https://doi.org/10.1086/687578

[28] Digital Architecture Roadmap. (2025). Digital Agriculture Roadmap (DAR) 2025–2032. Ethiopian Agriculture Transformation Institute. https://dar.ati.gov.et/resource

[29] Agri-Stack. (22 April 2025). Latest Updates on Agristack India 2025. https://agristack.co.in/latest-updates-on-agristack-india/

[30] PIB Delhi. (13 December 2022). Agristack Project. Ministry of Agriculture & Farmers Welfare. https://www.pib.gov.in/PressReleasePage.aspx?PRID=1883173&utm

[31] Business Standard. (17 December 2024). Over 3.7 Million Farmer IDs Created So Far Under 'Agristack' Project: Govt. Press Trust of India. https://www.business-standard.com/industry/agriculture/over-3-7-million-farmer-ids-created-so-far-under-agristack-project-govt-124121700897_1.html?utm_source=chatgpt.com#goog_rewarded

[32] Vaazhndhu Kaattuvom Project. (17 April 2023). Matching Grant Program Operational & Credit Guidelines. https://www.vkp-tnrtp.org/wp-content/uploads/2023/10/MGP-Guidelines.pdf

[33] Vazhndhu Kattuvom Project. (2022). Touching 3,10,909 Women's Lives in Rural Tamil Nadu. https://old.tnrtp.org/2023/03/10/touching-310909-womens-lives-in-rural-tamil-nadu/

[34] MicoSave Consulting. (19 May 2025). An Integrated Digital Platform that Simplifies Vital Agricultural Services for Indian Farmers. https://www.microsave.net/signature_projects/an-integrated-digital-platform-that-simplifying-critical-agricultural-services-for-indian-farmers/

[35] Kenya Agricultural and Livestock Research Organization. (2025). Kenya National Farmer Registration. National Agricultural Dashboards. https://www.kalro.org/kiamis/dash_hh_crops.html

[36] Dominique Arrouays, et al. (March 2020). Impressions of Digital Soil Maps: The Good, The Not So Good, and Making Them Ever Better. Geoderma Regional 20, e00255. doi: https://doi.org/10.1016/j.geodrs.2020.e00255

[37] Michaela Buenemann, Marina E Coetzee, Josephat Kutuahupira, Jonathan J Maynard, and Jeffrey E Herrick. (January 2026). Errors in soil maps: The need for better on-site estimates and soil map predictions. PLOS One 18(1), e0270176. doi: 10.1371/journal.pone.0270176

[38] Jiachen Yang, et al. (October 2022). Data Quality Assessment and Analysis for Pest Identification in Smart Agriculture. Computers and Electrical Engineering 103, 108322. doi: https://doi.org/10.1016/j.compeleceng.2022.108322

[39] Yang Li and Xuewei Chao. (24 December 2021). Toward Sustainability: Trade-Off Between Data Quality and Quantity in Crop Pest Recognition. Front Plant Science 12, 811241. doi: 10.3389/fpls.2021.811241

[40] Agricultural Markets Instability: Revisiting the Recent Food Crises. (2016). Routlage, Taylor and Francis Group. https://www.routledge.com/Agricultural-Markets-Instability-Revisiting-the-Recent-Food-Crises/Garrido-Brummer-MBarek-Meuwissen-Morales-Opazo/p/book/9781138588943?srsltid=AfmBOooYRTPQmHvmGwwxl6JVD052o_oNteHfPX5-SH1msWkiEsUccbxa

[41] Rabah Arezki, Karim El Aynaoui, Yaw Nyarko, and Francis Teal. (07 July 2016). Food price volatility and its consequences. Oxford Economic Papers (68)3, 655–664. doi: https://doi.org/10.1093/oep/gpw019

[42] Stephen Robert Miller. (24 October 2024).This App Set Out to Fight Pesticides. After VCs Stepped In, Now It Helps Sell Them. Wired. https://www.wired.com/story/plantix-pesticides-venture-capital-app/

[43] Co-Develop and the Digital Impact Alliance. (2024). Digital Public Infrastructure Evidence Compendium. https://drive.google.com/file/

d/18sYFCLl9ft2JsvEj5Ia3-F7hhAIvG4-F/view

[44] *Shagun. (24 June 2021). AgriStack: Linking land records with database will exclude labourers, farmers, warn experts. https://www.downtoearth.org.in/agriculture/agristack-linking-land-records-with-database-will-exclude-labourers-farmers-warn-experts-77645*

[45] *Shreehari Paliath. (12 January 2022). Digital AgriStack Could Help Farmers Access Services. Here's Why They Aren't on Board. India Spend. https://www.indiaspend.com/agriculture/a-digital-agristack-could-help-farmers-access-services-heres-why-they-arent-on-board-797287?.*

[46] *Karthik Muralidharan, Paul Niehaus, and Sandip Sukhtankar. (October 2016). American Economic Review 106(10), 2895–2929. doi: http://doi.org/10.3886/E113012V1*

[47] *Better Than Cash Alliance. (1 November 2013). Sustained Effort, Saving Billions: Lessons from the Mexican Government's Shift to Electronic Payments. Case Study: Mexico. https://www.betterthancash.org/explore-resources/sustained-effort-saving-billions-lessons-from-the-mexican-governments-shift-to-electronic-payments.*

[48] *Julia Clark and Georgina Marin. (12 September 2023). Why This Matters: Evidence Building on DPI. World Bank. https://thedocs.worldbank.org/en/doc/8325e21eaf7ab04cd8a8eede4d5e06da-0050112023/original/DPI-Workshop-Why-this-matters-Julia-Clark-Georgina-Marin.pdf*

[49] *Ugo Gentilini. (July 2022). Cash Transfers in Pandemic Times: Evidence, Practices, and Implications from the Largest Scale Up in History. World Bank Group. https://documents1.worldbank.org/curated/en/099800007112236655/pdf/P17658505ca3820930a254018e229a30bf8.pdf*

[50] *PIB Delhi. (21 April 2024). India's DBT: Boosting Welfare Efficiency: Report Reveals ₹3.48 Lakh Crore in Savings and 16-Fold Increase in Beneficiaries. Ministry of Finance. https://www.pib.gov.in/PressReleseDetailm.aspx?PRID=2123192#:~:text=%2A%20PM,8%20crore%20through%20targeted%20disbursement.*

[51] *Silvia Baur-Yazbeck, Emma Wadie Hobson, and Mutale Chimba. (April 2021). The Future of Government-to-Person (G2P) Payments: Three years of learning about G2P choice in Zambia. World Bank Group. https://www.findevgateway.org/sites/default/files/publications/2021/Disclaimer_The-Future-of-G2P-Payments-Zambia.pdf*

[52] *World Economic Forum. (16 January 2024). Farmers in India are Using AI for Agriculture – Here's How They Could Inspire the World. https://www.weforum.org/stories/2024/01/how-indias-ai-agriculture-boom-could-inspire-the-world/#:~:text=The%20pilot%20took%2018%20months,boosted%20unit%20prices%20by%208*

[53] *Leora Klapper, Dorothe Singer, Laura Starita, and Alexandra Norris. (2025). The Global*

Findex Database 2025. World Bank Group. https://www.worldbank.org/en/publication/globalfindex

[54] *Identification for Development. (March 2022). Using Biometrics to Deliver Cash Payments to Women: Early Results from an Impact Evaluation in Pakistan. World Bank Group. https://documents1.worldbank.org/curated/en/099155004142238180/pdf/P1763410d1e1af00108e170e5754d04fed9.pdf*

[55] *Jenny C. Aker, Rachid Boumnijel, Amanda McClelland, and Niall Tierney (October 2016). Payment Mechanisms and Antipoverty Programs: Evidence from a Mobile Money Cash Transfer Experiment in Niger. Economic Development and Cultural Change (65)1. doi: https://doi.org/10.1086/687578*

[56] *ibid.*

[57] *Ritul Gaur and Mansi Kedia. (24 April 2025). Making DPI Sustainable. The Indian Express. https://indianexpress.com/article/opinion/columns/making-dpi-sustainable-9961880/*

[58] *PIB Delhi. (1 April 2025). Digital Identities to Farmers. Ministry of Agriculture & Farmers Welfare. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2117390&*

[59] *PIB Delhi. (13 June 2025). National Conference on Agri Stack: Turning Data into Delivery. Ministry of Agriculture & Farmers Welfare. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2136255&*