Digital Agriculture Innovation Ecosystems

Summary Report

Agriculture and Food Global Practice
Data-Driven & Digital Agriculture Team
(DDAT)

Zina AKROUT & Bruno PAZ

May 2021

THE WORLD BANK
IBRD • IDA | WORLD BANK GROUP

Table of Content

This report was written based on the findings and interviews conducted during the elaboration of the Digital Agriculture Innovation Ecosystem case studies of Australia, Chile, France, Israel, the Netherlands and South Korea. Bibliographical references are the ones of these reports.

List of Tables

List of Figures

Abbreviations & Acronyms

aT	**Korea Agro-Fisheries & Food Trade Corporation**
ARO	**Agricultural Research Organization (Volcani Institute)**
EPIS	**Korea Agency of Education, Promotion and Information Service in Food, Agriculture, Forestry and Fisheries**
FACT	**Foundation of Agri-Technology Commercialization & Transfer**
FAO	**United Nations Food and Agriculture Organization**
INSEAD	**Institut européen d'administration des affaires**
IPET	**Korea Institute of Planning and Evaluation For Technology in Food, Agriculture and Forestry**
KTC	**Korea Trade Commission**
KREI	**Korea Rural Economic Institute**
MAFRA	**Ministry of Agriculture, Food and Rural Affairs**
OECD	**Organisation for Economic Co-operation and Development**
R&D	**Research & Development**
RDA	**Rural Development Administration**
UN	**United Nations**

Introduction

The food and agriculture sector faces many challenges. The world's population is expected to grow from 7.6 billion in 2018 to more than 9.6 billion in 2050; therefore, the demand for food is expected to increase significantly.

At the same time, natural resources, including fresh water and arable land, are under increasing pressure. Production is not the only issue: agricultural production is now sufficient to feed the world, but 821 million people still go hungry3. Phenomena such as the rapidly increasing rate of urbanization also have important implications for food production and consumption structure.

The agri-food sector remains a crucial sector for livelihoods and employment. Globally, there are more than 570 million smallholder farms[3], and agriculture and food production occupy a total of 28 percent of the global labor force 5. If "a world without hunger" is to be achieved by 2030, in line with the UN Sustainable Development Goals, more productive, efficient, sustainable, inclusive, transparent, and resilient food systems will be needed. To achieve this goal, there is an urgent need to transform the current agri-food system.

Today, the agricultural sector is faced with multiple uncertainties related to the transformation of world markets, new societal expectations for products and services, the growing importance of environmental issues, adaptation to global changes, changes in national and international public policies, and changes in the sociological profiles of farmers. Moreover, this sector is concerned by new forms of innovation, seeking to improve the productivity of farms while reducing their environmental impact. For example, the development of information and communication technologies towards digital agriculture opens up new perspectives, even if they are not the only ones, and are the subject of more and more research and development work. The growing importance of public-private partnerships and new research arrangements is gearing public research to create innovations and strengthen synergies with private players (start-ups, agri-food, and agri-supply industries), which account for a significant proportion of R&D investment. In this changing context, the research and development system must adapt to respond to the new issues expressed by farmers, public authorities, and other stakeholders.

This report is part of the World Bank's Agriculture and Food Global Practice activities and builds on the work carried out by the Data-Driven and Digital Agriculture Team (DDAT) on digital

agriculture worldwide. The World Bank's DDAT has decided to look into technological, organizational, and institutional innovations supporting the development of a thriving agro-food tech ecosystem in 6 countries: Australia, Chile, France, Israel, the Netherlands, and South Korea. Through case studies focusing on each country, this collective work will constitute a tool for reflection and orientation of strategic decisions for the actors of digital agriculture innovation ecosystems worldwide.

The case studies were produced through literature review, research, analysis, and interviews with different stakeholders from various sectors that play a role in the agro-food value chains. Interviews were conducted with a vast group of organizations and institutions from both the public and private sectors: government agencies, ministries, universities, technical institutes, interface structures between research and advice, think thanks, start-ups, innovations hubs, NGOs, to name a few. Farmers and their farms, often the primary beneficiaries of the research and development and innovation ecosystem, were considered actors in their own right, producing innovations but were not interrogated in this study. It is, therefore, a complex constellation of organizations whose dynamics had to be understood and analyzed.

While the study does not formulate policy recommendations, it does allow organizations involved in either research or advisory services to explore the current state of digital agriculture innovation ecosystems in the selected countries. This specific document summarizes the findings regarding digital agriculture transformation and the different innovation ecosystem models found in the studied countries.

Digital Agriculture Transformation & Innovation worldwide

Innovation is generally conceived as the transformation of an invention or idea into a usable and used product through complex interaction processes between actors. The Oslo Manual (OECD 2005) defines four types of innovation: **product** innovations, **process** innovations, **marketing** innovations and **organizational** innovations**.** The "push of technological innovations" thus includes:

- The dynamics of research, producing scientific advances (new knowledge)
- The emergence of new technologies (development)
- Dissemination of knowledge and technology to potential users
- The appropriation of knowledge and technologies by the actors and the emergence of new practices and uses

The Global Innovation Index is published each year by Cornell University, INSEAD, and the World Intellectual Property Organization (WIPO). It is a leading indicator of an economy's ability to innovate in several sectors of activity. All the analyzed countries in our studies rank "well" in the annual innovation ranking of 131 economies.

Table 1: Global Innovation Index 2020 rankings

Ranking	Country	Global Innovation Index
1.	Switzerland	66.08
2.	Sweden	62.47
3.	United States of America	60.56
4.	United Kingdom	59.78
5.	**Netherlands**	**58.76**
6.	Denmark	57.53
7.	Finland	57.02
8.	Singapore	56.61
9.	Germany	56.55
10.	**Republic of Korea**	**56.11**
12.	**France**	**53.66**
13.	**Israel**	**53.55**
23.	**Australia**	**48.35**
54.	**Chile**	**33.86**

Given the importance of innovation in business planning and national economic development policies, there is reason to believe that innovation will not suffer from the COVID-19 as severely as predicted.

Fundamentally, the pandemic has not changed the fact that there is already much room for breakthrough technology and creativity. Top corporations and R&D spenders would be foolish to abandon R&D, IP, and creativity in their attempt to maintain future productivity. Many leading R&D companies in the information technology industry have sizable cash reserves, and the drive toward digitalization would boost innovation. Another major R&D spender, pharmaceuticals and biotechnology, is expected to see increased R&D spending due to the renewed emphasis on health R&D. Other critical industries, such as transportation, will have to change more quickly as the search for "clean electricity" resurfaces. Furthermore, the COVID-19 crisis can spark innovation in various industries, including travel, education, and retail. It may also inspire new ideas about how work is structured at the firm and individual levels and how outputs are (re)organized locally and internationally. Unleashing the above capacity is now critical, and it will need government funding, collaboration models, and continued private sector innovation spending.

The effect of the economic recession on start-ups, venture capital, and other sources of innovation funding is a central issue considering the numerous questions and ongoing debates around innovation financing. The positive thing is that, unlike in 2009, the financial sector seems to be in good shape so far, but funding for "creative" projects is becoming scarce. Venture capital (VC) transactions are on the decline in North America, Asia, and Europe. When exit strategies such as IPOs become less appealing to—and lucrative for—venture capitalists in 2020, the start-ups that remain will become less desirable to—and profitable for—venture capitalists.

Surprisingly, the recession has just exacerbated a downturn in venture capital transactions that began before the pandemic. Rather than investing in new, tiny, and diverse start-ups, venture capitalists began to concentrate on so-called "mega-deals," which include raising a small number of big companies rather than providing new funding to a more significant number of start-ups. These acquisitions and the pursuit of so-called "unicorns" did not pan out as planned. What does the future hold for venture capital, both now and in the future? A possible response is that venture

capital costs would take longer to recover than R&D costs. The influence of the innovation finance deficit will be unequal, with early-stage VCs, R&D-intensive start-ups with longer-term research interests in fields such as life sciences, and projects outside of the top VC hotspots the brunt of the negative consequences. Indeed, existing VC investments are concentrated in a few VC hot spots worldwide, and only a few of those hot spots are in developing economies, especially BRICS. There are, though, reasons to be optimistic. The studied country, especially Israel, will continue to attract venture capital. They are expected to recover soon, owing to the global need for returns on capital. Significantly, the focus of venture capital and engineering seems to have shifted to fitness, online education, big data, e-commerce, and robotics.

What about innovation in agriculture? As mentioned above, innovation is generally perceived as being related to technology. The definition of innovation is much broader. *Agricultural innovation* is the process by which individuals or organizations implement for the first time new or existing products, processes, or organizational modes in a specific context to increase efficiency, competitiveness, and resilience to solve a problem. International institutions related to food and agriculture advocate the importance of innovation in agriculture to improve food security, sustainable development and promote rural development. Innovation in agriculture affects all dimensions of the production cycle and the entire value chain - from crops, forestry, fisheries, and livestock production to input management and market access. All countries should unleash the potential of innovation to stimulate socio-economic growth, ensure food and nutrition security, reduce poverty, and improve resilience to climate change, thereby contributing to the Sustainable Development Goals (SDGs) achievement. Because innovation is a complex process in which governments and other key actors play different roles, a systemic approach is needed.

To improve the productivity of their farms, farmers are moving towards precision agriculture thanks to Big Data collection. While grain company Monsanto announced in 2013 that it was buying Climate Corp (a data analysis company) for nearly $1 billion, start-ups are springing up to foster the link between the Internet of Things, Big Data technology, and agriculture. This trend echoes a transformation of this centuries-old industry as a new local consumption pattern emerges in developed countries. A new generation of farmers integrates more connected objects to improve farm performance. Thanks to the falling cost of connected sensors collecting various data

(meteorological, soil condition, pollination), a system for analyzing and forecasting hazards that can influence agricultural yields is becoming more accessible to all farmer profiles, allowing the emergence of precision agriculture. In parallel with the development of sensors for data acquisition and real-time monitoring, progress has been made on the relevant analysis of the data collected, enabling us to move from measurement to a proposal for action. At present, the data flows generated on farms are mainly used by the companies that produce agricultural equipment and measurement systems.

Computerization of farms and the rise of the internet

Development of technical decision support tools (farmers, economic actors), models/simulators (expertise support, public policy support), and multi-criteria evaluation tools have revamped agriculture worldwide. Many "general public" technological innovations, originating from other industrial sectors (telecommunications, health, etc.), arrive at the farms and sectors later but find applicability.

The digital revolution is transforming the jobs of farmers and advisors (training needs of farmers, renewal of support, etc.). Genomic engineering offers solutions to meet the needs of productivity, sustainable agriculture, and perhaps adaptation to climate change, such as developing varieties that require less water and pesticides and are more resistant to growing conditions. The development of genetically modified organisms (GMOs) will continue, even if the regulatory framework in Europe is not favorable at the moment. GMOs could be a credible solution to short-term climate change adaptation issues. Similarly, animal and plant breeding will continue with the appearance of new criteria with agronomic, health, and environmental benefits. Robotisation has already been identified as a critical area of innovation for competitiveness (reducing labor-related production costs), particularly in specific sectors, such as the fruit sector. In addition to the societal interest, robotic technologies in the agricultural industry are a significant economic challenge. According to the International Federation of Robotics (IFR), which each year analyses the robotics market and its prospects, all application sectors taken together, agriculture is the second-largest market for professional service robotics.

The agricultural sector will carry out many innovations that meet the objectives of agroecology (producing more with fewer inputs). The emergence of precision agriculture and digital agriculture technologies will facilitate agroecological practices by overcoming certain technological or organizational obstacles. Overall, there is a « greening » movement around new technologies that enable their acceptance by society and comply with regulatory requirements. In addition to this, we have witnessed a strong diversification of innovation producers (non-agricultural companies, etc.) with the opening of the agricultural sector to new players (Google, Amazon, etc.) There is a strong involvement of some farmers in the development of innovations. Co-design approaches are be put worldwide to adapt or produce new practices or equipment moving towards agroecology. This is why the mechanisms enabling R&D to perceive innovations in the field will increase in the coming years.

Digital agriculture innovation ecosystems and their challenges

The term "innovation ecosystem" has become a buzzword, not always with the same meaning but based on an analogy with the natural world. In biology, it refers to a system formed by an environment and all its species. Imported into the vocabulary of business and applied to innovation, it is generally used to designate a set of actors - organizations, companies, start-ups, universities, investors, resource persons - that interact in favor of innovation.

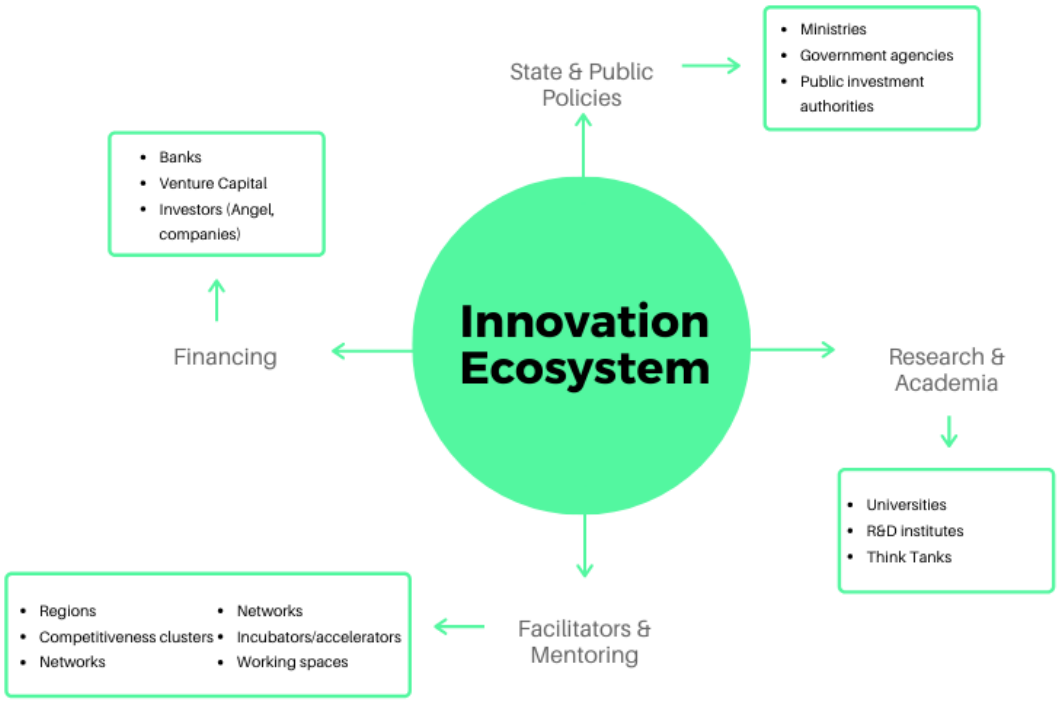

Figure 1: Representation of an innovation ecosystem based on our countries' analysis

Digital agriculture, in addition to being a global agricultural development issue, is also a political and strategic issue for many countries, including those analyzed in our study. Indeed, it represents a priority objective in terms of innovation in agricultural policies and involves different actors who interact in the innovation process. A new ecosystem of actors and services is being set up to support this technological transition. Reflections on the development of digital agriculture raise questions about the sectoral dynamics underway, the new configurations of actors, and the evolution of the institutional environment.

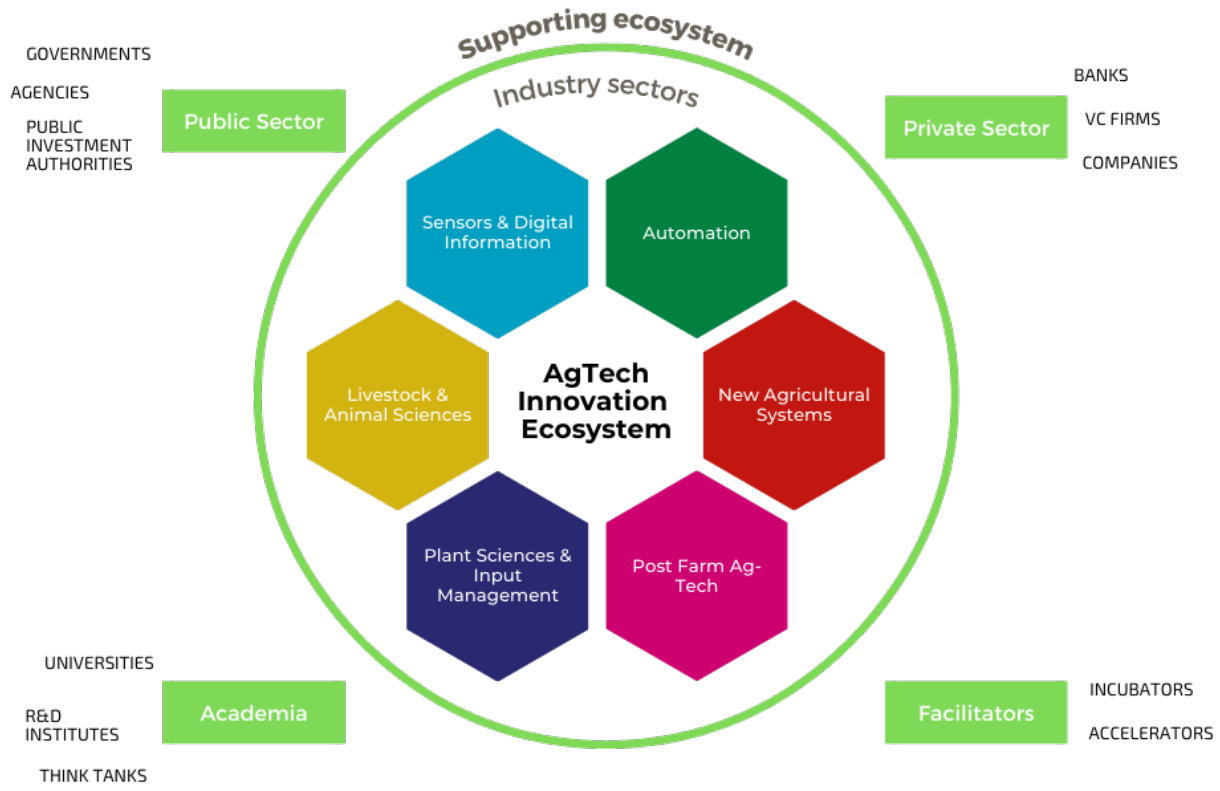

Figure 2: Representation of a digital agriculture innovation ecosystem based on our countries' analysis

As described before, the digital agriculture ecosystem encompasses three main stakeholders: the government, the private sector, and the academia. Each stakeholder has its interest and role in promoting and supporting digital agriculture transformation. The importance of highlighting and recognizing the drivers that mobilize different sectors within the digital agriculture ecosystem relies on its potential to foster collaborations.

Worldwide governments have shown interest in digitalizing the agriculture industry. Governments see digital agriculture as a source of data and information for better policymaking. Moreover, digital technologies can help to achieve SDGs by providing accurate and real-time data for better farming and logistics management along the whole food supply chain. In addition to all this, digital agriculture transformation can address some of the most common problems in the global food system. For example:

1. Increase production per hectare at lower costs: digital technologies and analysis of accumulated farm data can lead to better in-farm decision making increasing input-output productivity. Consequently, food production and food exports increase, and food price decreases.

2. Protection of natural ecosystems: farmers tend to overuse inputs such as fertilizer or pesticides when information is not sufficient. These unsustainable practices allow farmers to deal with the potential lack of soil nutrients without any available information. Consequently, the overapplication of inputs might affect the natural ecosystem, especially water bodies (e.g., runoff, lixiviation, draining into groundwater bodies and aquifers, etc.). Having accurate data of how much input is needed to maximize production per hectare would help farmers increase their production, decrease production costs, and reduce agricultural pressure on the environment.

3. Food supply logistic management: information on how much is produced, how much is transported, how much needs to be stored, the origin of the product, the quality of the product, real-time location of the commodity, and any other logistics-related information, can help to alleviate inefficiencies along the food supply chain, providing clear information for potential investments and logistics management and, in long-run, reducing waste.

4. Rural employment: digital agriculture is expected to automatize many rural jobs, for example, by using self-driving tractors. However, digital agriculture will lead to "creative destruction," creating new jobs in rural areas which require new skills in data management, agriculture, and robotics.

5. Rural migration: digital agriculture can reduce rural migrations by increasing the quality of life of the people who live in rural areas. Some countries, such as South Korea, aim to address youth migration from rural to urban areas by promoting digital agriculture transformation.

6. Innovation: Innovation requires the co-participation of different stakeholders and, in the short run, it represents financial investments, jobs creation, HR training, and tax revenue, whereas, in the long run, it means economic development, increased exports, and whatever benefits the technology can potentially bring to the country.

Governments and public institutions will commonly reallocate and mobilize financial and human resources to foster digital agriculture transformation accordingly to a national policy framework. Typically, governmental agencies deploy different strategies to support innovators (e.g., start-ups) and final users (e.g., farmers) in the digital agriculture ecosystem. They supply the ecosystem with financial support, grants, technical assistance to farmers, and incubating and accelerating IT companies.

On the other hand, the private industry is another important stakeholder in the digital agriculture ecosystem. As mentioned before, the private sector is diverse. It includes IT firms, service providers, start-ups, venture capital firms, agricultural advisors, farmers, and final users. In general, the main driver for the private sector to support digital agriculture transformation is its potential for maximizing profit. In other words, revenue maximization, cost minimization, or both. Privates together are usually strong enough to replicate the public support strategy aiming for profit. Venture Capital firms provide financial support and play a role in accelerating, incubating, and investing in start-ups. Agricultural advisors offer technical assistance to farmers. On the other hand, engineers develop technology in the private industry. Start-ups innovative and create new digital tools for the sector. However, the primary determinant of digital agriculture transformation is final users. Final users are primarily farmers and firms along the whole supply chain, and when they adopt digital technologies, they reap the benefits from them.

As described above, final users are mainly driven by profit maximization. In an in-farm context, it means farmers adopt digital technologies for data-driven and better decision-making. In doing so, they aim to reduce costs, increase total factor productivity, reduce time and labor allocation to farming, and increase technical and allocative efficiency while producing in a sustainable and

environmental-friendly way. Moreover, digital technologies have also been used by final users to digitalize payment methods and better data-driven logistics management, leading to a more efficient supply chain and a lower transaction costs system.

Last but not least, universities and research institutions aim to promote innovative solutions by answering high-complexity questions and supporting new technology development. Academia sees digital agriculture as a response to a need of the agricultural industry. The contribution of academia to digital agriculture transformation has been meaningful worldwide. Universities and research institutions have been responsible for providing the digital agriculture innovation ecosystem with the most skilled people and advanced infrastructure for research purposes. They also support the ecosystem in developing digital agriculture technology scaling-up strategies and linking the most advanced science with the private industry. One relevant example is Innovation Hubs all over the world, in which academia plays an important role.

Even though we provided a general and broad definition of why stakeholders are interested in promoting digital agriculture, their roles may vary country by country depending on socio-economic and historical context. Table 2 provides a summary of the particularity of the innovation ecosystem in 6 countries.

.

Table 2: Summary of the particularity of the innovation ecosystem in the study case countries

Country	Particularity of the innovation ecosystem	Scope of innovation
Australia	• The government promotes PPS and independent research on DA. • The private sector creates and disseminates digital technology, provides investment, technical assistance, and increases digital infrastructure. • Academia supports PPS by providing highly skilled people and advanced infrastructure.	National and by industry
Chile	• The government injects money and provides technical support following a decentralized approach. • The private sector creates and disseminates technology, invests, creates innovation hubs, and provides technical assistance to final users. • Academia does research, creates technology, disseminates technology, provides solutions by promoting digital agriculture technologies, trains and educated future generations.	National and local
France	• The national ecosystem is favourable to innovation (e.g. RMT, UMT, GIEE, competitiveness clusters etc.) and is well connected to the other EU Member States (EIP). • The country is fostering digital innovation to improve social, economic and environmental performance of agriculture • The ecosystem is cluster-based & research oriented • Fundings mostly comes from the public sector (although VC are growing in France) and is deep-tech oriented.	National (Local) & Regional (EU)
Israel	• The country's dynamic is of applying technology to agriculture and exporting their agricultural technology and production systems • Innovation is R&D and business oriented, mostly managed by specialized Israeli research institutions (Volcani Center – ARO) • The government is setting up and funding AgriTech incubators and the Israeli ag-tech VC landscape is rich with local and international firms.	National & International
The Netherlands	• The government, business, and research institutions strongly collaboration for the country's Agri policy. The Government plays an important role in Agricultural innovation, but is not interventionist • There is a solid overall PPS-academia cooperation, notably an academic-entrepreneur collaboration dynamic (especially in the Food Valley NL with Wageningen University). • The NL differentiate themselves in AgTech by creating a scalable model that can be applied through many geographies. • The country's main focus is digitising precision agriculture and livestock breeding • Funding is Public & Private, although VC funds are not very much available in the country due to its market size and Technology&Material focus	Regional (EU) & International
South Korea	• The government is the leading player in the country. Responsible for creating digital tools, disseminating, creating data platforms, and installing digital infrastructure. • The private sector is relatively less important than in other countries, "filling the gaps," and relatively independent from the government. • Academia is responsible for creating technology and supporting private companies to do the same. It does research, creates innovation hubs, trains, and educates new generations.	National and international

What are stakeholders doing?

Table 3: Summary of DA relevant projects in 6 different countries

Country	Year	Project title	Stakeholders	Project description
Australia	Created in 2017	FoodAgility CRC	Private industry, academia and public sector.	FoodAgility is a $150million+ Cooperative Research Center (CRC) focused on creating new digital technologies and services to benefit the Australian agrifood industry. FoodAgility works on the basis of co-investment between government, industry, researchers, and final users. The collaboration aims to deploy an agile delivery framework. FoodAgility support digital tool developments, answer high-complexity questions, and support final users to find optimal solutions by adopting digital technologies. This CRC mainly works with scale-up companies and does not work with start-ups.
Chile	Created in 2018	ThinkAgro	University of Talca, Chilean Government and private industries	ThinkAgro is a technological extension center and it was created under the innovation and technology extension policy of the Chilean government. ThinkAgro links individuals and institutions needing technological solutions to the optimal technical solution using digital agriculture technologies. This extension center develops a diagnosis, propose a solution, provide a service and evaluate the solution's impact. ThinkAgro developes digital tools to provide solutions to the problems. Moreover, ThinkAgro has a pool of companies that can offer solutions to final users if ThinkAgro cannot provide an optimal solution first.
France	Created in 2020	Chaire/Alliance H@rvest	Public, private & research: AgroParisTech, the AgroParisTech Foundation, the IRT SystemX, Télécom Paris and Terres Inovia	To face the agricultural and food challenges of today and tomorrow, the H@rvest Alliance aims to support digital technology for the benefit of the agricultural sector to optimise the strategy, management and conduct of farms and chains of players. The H@rvest Alliance combines the strengths of a chair of (applied) research sponsorship dedicated to the general interest and innovation projects financed by industry and the future investment programme. The two operational and funding methods are complementary and inseparable for the members of the Alliance, who ensure their coherence.
Israel	Created in 1979	MIGAL Galilee Research Institute	Research, public & private	MIGAL is an independant agency that conducts academic research, agricultural research and development, and technology transfer, as well as providing incubation services. MIGAL specializes in ag-tech, bio-tech, and nutrition studies, with a focus on agriculture and environmental sciences as it designs industry-specific technology solutions. The institution is a key participant in a wide range of local and international programs, such as seminars, forums, and fairs that put together growers, educators, researchers, and entrepreneurs.
The Netherlands	Created in 2020	FoodSwitch	Public, private & research: TU/e-JADS, WUR, UU, AgriFood Innovation Initiative, Regiodeal Foodvalley, Regiodeal Brabant, Taskforce Korte Keten , Transitiecoalitie Voedsel, Sustainable Food Initiative, FoodValley, AgriFoodCapital, World Food Center, Utrecht Food Freedom, Future Food Lab	In September 2020, the Dutch government unveiled a new business and innovation investment fund, the Growth Fund, to accelerate economic growth in the Netherlands after COVID-19. The Dutch agri-food industry focuses on FoodSwitch, a large-scale cooperative innovation initiative with a strong chance of receiving funding from the Growth Fund. As a result of the required transition to a sustainable global food supply, FoodSwitch aims to create new business models and earning potential. The Netherlands now has a rare opportunity to lead the global transformation to a sustainable food environment as a leading nation in AgriFood, Horticulture, and HighTech. The FoodSwitch program allows businesses to build infrastructure, manufacturing processes, and methodologies, then introduce them to foreign markets, allowing

			Utrecht, DVG, Citydeal Voedsel op de stedelijke agenda, Greendeal Natuurinclusieve landbouw in het Groene Onderwijs, Regiodeal Bodemdaling, RIVM, AI Coalitie, Provincial & municipal governments (Utrecht, Amsterdam, Almere, Den Bosch), Boerencollectieven (farmers collectives), retail Makro, CLI, branch organizations : primary agriculture, food industry (startup, SME, large), banking, insurance.	for more efficient local food production worldwide. Under the FoodSwitch scheme, FoodUnites is a critical project line and roadmap. The FoodUnites' strategy focuses on increased accuracy and the development of new supply chain relations, made possible by rapid advances in high-tech, digitization, and artificial intelligence (AI). In this approach, value chain convergence is critical, as it allows operations in individual links in the value chain to be optimized, from plants, fertilizers, and (precision) manufacturing, to manufacturing processes and residual flows, to customer awareness and supermarkets. This necessitates digitization to allow for the organized sharing and analysis of data in the supply chain – both upwards and downwards – allowing for new value and revenue models to emerge (e.g., demand-driven product development).
South Korea	To be completed on 2022	Smart Farm Innovation Valley	MAFRA, RDA, FACT, EPIS, IPET, KTC, and local government.	This project aims to contribute to the growth of IT and Ag-Tech businesses and farmers, encouraging youth entrepreneurship and job creation through smart farm technology innovation and localization, and helping South Korean companies to try overseas markets. The Government plans to establish 4 Smart Innovation Valleys before 2022 across the country. The Smart Farm Innovation Valleys will at least consist of a “smart farm for lease”, a “demonstration complex”, and an “incubation center”. These three elements aim to serve as a base to create synergy among farmers, companies, and research institutes, focusing on integrating smart farms, youth start-ups, technological innovation, and market development.

Conclusion and challenges in the establishment of sound digital agriculture innovation ecosystems

How to make good use of an innovation ecosystem?

More and more innovations are ecosystemic: various players who do not belong to the same industry and who are not used to work together combine their actions to provide a coherent solution to a given end goal or customer. The development of mobile payment involving telecom operators, banks, payment institutions, equipment manufacturers, and merchants is a good example. Examples of such ecosystems are numerous and well-known. However, much less is known about how these ecosystems came into being and how the innovations were designed upstream. Moreover, for a good reason, this emergence phase is very complex. Indeed, the scope of the innovative solution has not yet been stabilized. The potential contributors to this offer have not all been identified, and the rules between them have not yet been fully defined.

According to the countries analyzed and the people interviewed, innovations in the agricultural sector are emblematic of ecosystem innovations because they involve a variety of actors, including producers/farmers, those who package and transport foodstuffs, the engineers in charge of developing tools and technologies for farming, and their suppliers the end-users of the services/commodities produced, etc. They also involve the public authorities that regulate the functioning of the agricultural system in a given country and private actors such as investment funds or banks that often finance the research and development of technologies.

Experimentation and prototyping play a driving role in the emergence of the ecosystem and its consolidation and the reduction of uncertainties for the actors, contributing to "sustainable" innovation *(cf. The Netherlands)*. Indeed, during the emergence phase, companies are faced with multiple uncertainties. They lack knowledge about the context in which the innovation will be used, its impact on overall performance, the performance criteria valued by the customer, the costs and conditions for using the innovation, etc. Beyond the technical domain of the various agricultural innovations, four specificities that are useful for the emergence of ecosystems can help actors in their innovation process can be noted:

1- **Stakeholders engagement**

For an experiment to increase knowledge about the solution and the underlying ecosystem, stakeholders must be involved in each of the components of the offer. This allows the interdependencies between the different elements to be highlighted, which can impact the solution's overall performance. However, the companies involved in the experimentation are not necessarily those that will ultimately contribute to the marketed solution.

2- **Conducting experiments with complete solutions**

A given innovation must be as close as possible to an industrial solution. For this, it is essential to implement a complete solution. It is therefore not possible to conduct these experiments very far upstream. In this sense, they are different from "low-cost probes," the basic prototypes often put forward. Experiments generate knowledge about the context of the innovation, the conditions of its implementation, the performance valued by the client, its operating costs, etc. They thus make it possible to test innovations before they are implemented and before considering other more massive applications. However, they do not constitute a pre-commercial solution used to validate functional performance. They enable the overall performance to be evaluated and identify what needs to be improved or added, and consequently, the associated players. *(cf. IL/ NL projects)*

3- **Involvement of "real" customers**

For experiments and innovations to generate useful knowledge, it is necessary to work with 'real' customers who are willing to use prototype solutions in current conditions for a significant time. This is a prerequisite for getting feedback on outstanding issues and refining the value proposition for the customer.

4- **Data-use transparency**

One of the primary objectives of the experimentation phase in innovation is to reduce uncertainty about the solution's performance and the nature of the relationships between the different players

in the innovation. For the latter to commit themselves, despite a climate of uncertainty, it is necessary to favor a maximum of transparency concerning the rules for sharing knowledge and the way it is used. This is a challenge for all the actors involved. To avoid conflicts and limit opportunistic behavior, it is essential to define, from the outset, how the various contributors will use the data.

In the digital field, pilots or proof-of-concept are increasingly giving way to MVPs (*minimum viable products*), which use the four lessons set out above, particularly the third, which consists of carrying out full-scale tests with real customers. All this also calls for a reflection on the digital transformation of organizations. The revolution in the Internet of Things, the cloud, and the codification of various sources of company data (application data, CRM, etc.), as well as external partners (social data, opinion data, etc.) or open data, implies the construction of relevant ecosystems of actors and data, which respond to business, innovation, and competitive advantage issues. These four lessons are potentially exploitable and appropriate in the context of data ecosystems, as they provide a framework for data research and data-driven innovation. Experimentation is therefore not only technically valuable. It allows for the development of innovation and the collaboration of different actors.

Challenges for Digital Agriculture innovation ecosystems

In theory, digital agriculture represents an opportunity for most countries to develop the agriculture industry by having accurate data available and ready to use. However, even though countless are the benefits of digital agriculture transformation, most countries face lower digital agriculture technology adoption rates than expected. Consequently, nations are missing the opportunity to reap benefits from digital agriculture technologies.

The lack of a robust data policy framework in most countries creates a lack of trust among farmers and privates. The agricultural industry and farmers are reluctant to share their farm data because it can represent a threat to their privacy and interests if it is misused (e.g., for taxation purposes). Moreover, farmers understand that value derives from data analysis, and third parties and big companies can use farmers' data to obtain asymmetrical and unshared benefits from it. Digital agriculture requires digital infrastructure (e.g., internet and mobile telecommunication infrastructure) to collect, transfer, and storage information and data. Most countries have a lack of digital infrastructure in rural areas representing an obstacle to digital technologies adoption. Even though telecommunication technologies that support digital technologies exist, it seems rural regions are not convenient (i.e., profitable) for service providers. The limitation is then who assumes the technical and investment risk when the expected revenue is somewhat low.

Furthermore, digital agriculture transformation requires data specialists that understand agricultural production systems. Furthermore, as highlighted by many countries, data scientists and agronomists seem to be two different worlds. The lack of skilled people who understand digital technology while understanding the agriculture industry and food supply systems and vice versa has undermined the value proposition of digital agriculture technologies. Value-proposition is an additional challenge that requires attention. Commonly, the understanding of the value proposition is the primary driver for any transformation. In other words, how do stakeholders benefit from transforming an analog system into a digital and automated system? There is a lack of clarity on the value that digital agriculture technologies might bring to the whole food supply system. Thus, it harms digital agriculture technology adoption rates.

Furthermore, due to the nature of digital agriculture technology, the added value might peak after several years of data collection. It is because an essential proportion of digital agriculture value proposition comes from data analysis and artificial intelligence. In this context, users and farmers have been reluctant to cooperate and share data with each other since the only added value they recognize at an early stage is the revenue from selling data.

In addition to all this, digital tools are knowledge-intensive technologies. In a context where poverty and lack of education are predominantly in rural areas comparing to urban areas, digital agriculture technology dissemination is triple-challenging:

1. As mentioned before, digital agriculture transformation relies on the visibility of the value proposition.
2. There is an aging rural population and generational issue. Commonly, older generations value their traditional practices and are more reluctant to adopt new technologies than younger farmers.
3. Digital technologies are sometimes complex to understand, especially for people who have not had access to formal education.

Finally, the low rate of investment in the agriculture industry, compared to other sectors, also represents an issue and a barrier for digital agriculture transformation. Even though digital technologies seem to have been recognized as a priority by many nations worldwide, the lack of financial resources for start-ups and farmers represents an additional barrier to digital agriculture innovation.

Recommendations

As mentioned before, connectivity and digital infrastructure in rural areas are barriers to digital agriculture transformation in most countries. Governments should consider deploying policies and investment package to secure adequate digital infrastructure in rural areas. Alternatively, telecommunication infrastructure tendering processes in the country should include in their agreements "digital infrastructure in rural areas." Moreover, governments can support farmers and private individuals in investing in technologies that boost connectivity in their farms by providing subsidies, grants, or tax relief programs.

Having a solid data policy framework in a country is essential to ensure the benefits are distributed equally among stakeholders and increase trust within the digital agriculture ecosystem. Consequently, stakeholders will be more willing to collaborate in a trustful environment. While laws and consistent policy frameworks might take longer than expected, the private sector and Farmers Federations should consider giving the first step and developing guidelines for farmers aiming to increase digital adoption in the farm sector, ensuring that farmers have confidence in how their data is collected, used and shared.

Academia is responsible for closing the gap between agronomists and data scientists by training future generations following a much holistic approach during their training programs. Although universities seem to be making an effort to teach future agricultural advisors, it might take several years before they are ready to support digital agriculture transformation. However, there are several actions that privates can take to help academia closing this gap. For example, digital technologies should include user guides, training, and technical support. Moreover, digital tool developers should allow final users to provide feedback (e.g., how user-friendly the technology is) before releasing the final version into the market. In addition to all this, private companies should consider collaborating to include interoperability features in their products. This would allow farmers to reap the benefits from several digital technologies at the same time.

In order to disseminate digital agriculture technology across the country, governments must be aware of farmers' demographic characteristics and pay particular attention to those social groups that are more reluctant to try and adopt new technologies. Usually, governments have public

institutions linked to the Ministry of Agriculture or equivalent organizations that aim to support development programs in rural areas. In most cases, these organizations have a support structure that provides technical assistance to farmers across the country. These institutions represent a backbone in digital agriculture transformation, especially in those areas where farmers are reluctant to try new technologies.

Last but not least, developing new strategies to clearly communicate the value proposition of digital technologies is a must in the process of digital agriculture transformation. Final users need to understand the gains and benefits of adopting digital agriculture technologies and how the value proposition of digital agriculture varies accordingly to the digital stage.

Closing remarks

Stakeholders do not play a single role within the digital agriculture innovation ecosystem. It varies country by country, and it seems to depend on their socio-economic conditions and their vision of economic growth. In any case, regardless of the approach followed by stakeholders, public institutions seem to be the ecosystem's backbone.

To foster digital agriculture transformation, governments worldwide have used strategies to promote public-private partnerships, provide grants and technical assistance to farmers and privates and public institutions; or in specific cases, the government is the leading player responsible for carrying forward transformation. On the other hand, academia seems accountable for educating and teaching future generations and supporting the existing digital agriculture ecosystem with their researchers and skilled people. In specific cases, academia plays even a more relevant role in disseminating digital agriculture technologies and linking technologies and final users' needs across the country. Last but not least, privates are the foremost innovators in the ecosystem regardless of whether public institutions support them or not. An essential element within the private category is final users, such as farmers and ag-tech companies. These individuals adopt digital agriculture technology, collect data, and creates added value from it.

Although digital agriculture transformation is imminent, there are challenges that the countries still need to address to keep reaping benefits from digital agriculture technologies. These challenges include data policy, lack of value proposition, lack of digital literacy in rural areas, lack of connectivity, and lack of leadership and a policy agenda. Since the nature of these issues seems to be diverse, solutions will require to be as diverse as the challenges.