

THE DIGITALIZATION OF AGRICULTURE TOWARDS SUSTAINABLE AND EQUITABLE DEVELOPMENT: THE CASE OF COSTA RICA

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Abstract

The agricultural sector has been criticized for low productivity ratios and high environmental impacts, while it tends to be considered left behind by high-tech innovations as it's difficult to apply some of them due to social structure issues. Currently, the two main drivers for agricultural innovation are the bioeconomy and digital technologies, the former being widely explored, whereas the latter hasn't received as much attention, especially in developing economies. So, this paper aims to map the state of the digitalization of agriculture in Costa Rica and to establish its contribution to the sustainable and inclusive development of rural territories in Costa Rica. For this, a multiple-integrated case study design is followed, divided into three phases. First, a literature review. The second analyses the public policy space for the digitalization of agriculture from secondary data and interviews with policymakers and users. The third systematizes practical experiences; for this, in-depth interviews and field visits were carried out to cover the cases of the main five agricultural productions of the country, which represent more than 95% of its agricultural production. Finding that digital technologies can join economic and sustainability goals through an increase in the precision and information flow of the productive processes, promoting a better integration of the productive systems and ecosystems, bringing closer consumers and producers, etc. Yet, the country still lacks a public policy for the digitalization of agriculture, leading to a fragmented policy space that creates challenges in terms of inclusion.

Keywords: Digital agriculture, rural development, innovation, sustainable development, territorial development, public policy

Jel Classification: Q00, Q01, Q55

1. Introduction

The society undergoes continuous transformations, sometimes by the introduction of novelties; this transformative process originated by a novelty is innovation (Rodríguez-Soto, 2025; Saénz-Segura et al., 2024). Now, innovations occur at many levels; it's a broad concept (Rolandi et al., 2021). They can be changes in processes, techniques, technologies, organizational, or others, if they keep a societal scope (Rodríguez-Soto, 2025). When thinking about agricultural innovations, it's easy to see how they have

shaped human history, from enabling the transition from nomadic tribes to sedentary settlements by allowing to feed bigger cities to current high-tech solutions.

A major innovation for agriculture came to be during the 20th century, when agricultural production received a huge push with the development of chemical inputs that vastly enhanced productivity (Ravallion, 2015). These substances increased the production and made agricultural products accessible for many; this came to be known as the Green Revolution of agriculture (Chávez, 2019). The sudden increase in agricultural productivity became paramount for sustaining the opulent lifestyle of large conurbations.

But this novelty carried the seed of new problems, mostly environmental and public health hazards (Chávez, 2019; Rodríguez-Soto, 2025; Saénz-Segura et al., 2024). The intensive production and use of agrochemicals have negative effects on the soil composition, water footprints, biodiversity, public health, ecosystem services, and others (Chávez, 2019; Rodríguez-Soto, 2025). While, in terms of sustainability, agricultural activities are axial for ecosystem services; they provide them, but they're ecosystem services themselves (biomass production) (Hernandez, 2020). Agriculture is, in essence, the reconfiguration of the ecosystem services of a location to fit specific human needs, institutionalized in land use permits. All this leaves a Herculean trade-off to consider: modern society satisfies its needs with mass agricultural production, but mass production carries threats to the sustainability of nature and society.

Despite this complexity, recent rural and agricultural innovation trends offer a possible solution (Rodríguez-Soto, 2025). Present-day agricultural and rural innovations are empowered by three main drivers: bioeconomy, digital technologies (Goulet et al., 2019), and the orange economy (Benavente & Grazzi, 2017). The first two have great potential to join environmental and economic goals if properly channelled (Rodríguez-Soto, 2025). The bioeconomy has been widely studied in Europe (Giuntoli et al., 2023) and America (IICA, 2023), but the digitalization of agriculture remains relatively unexplored in Latin America, with some recent significant efforts (Le Coq et al., 2024). And despite the growing interest in digital agriculture, little is known about how it's shaping sustainability and inclusion in small developing economies, like Costa Rica. In fact, this is the first comprehensive study that examines the case from both the private and public perspective in the country.

Therefore, this paper aims to answer three questions: How is the digitalization of agriculture being implemented across major productions in Costa Rica? What sustainability and inclusion outcomes are being reported by key stakeholders? And how does the existing public policy shape and contribute to these transformations? To answer these, the research followed a multiple-integrated case study design (Yin, 2003), comprised of three phases: a literature review, an analysis of the public policy space (Fontaine, 2015), and a systematization of experiences (Schettini & Cortazzo, 2015) of the main agricultural productions of Costa Rica (covering cases representative of more than 95% of the national production).

Finding that the digital technologies can enhance productivity and sustainability simultaneously, and that these effects can be greater when combined with other innovation drivers, like bioeconomy. Yet, it's necessary to consider how to make these transformations work for all, otherwise they will just

further increase the breaches between big, medium, and small stakeholders (Saénz-Segura et al., 2024). In Costa Rica, in many cases this difficulty has been sorted out with alternative governance forms, like cooperatives, but still poses a major challenge due to the structural asymmetries of the population. In all, the potential of the digitalization of agriculture—and the inclusion challenges it faces—makes an urgent call for public policy interventions; right now, the country lacks a public policy for the digitalization of agriculture, which creates a fragmented policy space.

The next section synthesizes the theoretical framework, inquiring in the contribution of digitalization of agriculture to the sustainable development of rural territories. Section 3 presents the methodology and research design. Section 4 presents the results and Section 5 the discussion. Finally, Section 6 concludes.

2. Theoretical Framework: the digitalization of agriculture—sustainability and inclusion

The digitalization isn't a homogeneous phenomenon; it joins a great variety of transformations of different ranges of complexity. It covers several levels of application of digital technologies, like digitization (converting analogous information to digital formats), digitalization (new opportunities and business models), and the digital transformation (a systemic change in society by the integration of digital technologies) (Le Coq et al., 2024). Nonetheless, these apply to all types of economic activities and sectors; therefore, it's to be understood as a broad change or a new stage of societal development (Klerkx et al., 2019; Saénz-Segura et al., 2024; Ulezko et al., 2019).

So, digitalization shouldn't be thought of as a substitution of the old activities but as an enhancer of their possibilities (Roberts et al., 2017; Rodríguez-Soto, 2025; Ulezko et al., 2019). As such, the digitalization of agriculture is the result of the search for solutions and improvements empowered by digital technologies in the agricultural sector (Kuzmich, 2021; Vorobeva et al., 2021). It's possible to identify two broad categories of digitally empowered innovations in the agricultural sector by their area of impact: those that affect the productive systems and those that affect the value systems.

The first change the way of producing in a biophysical sense, modifying the efficiency, use of inputs, productivity, stability, and sustainability of production (Klerkx et al., 2019; Rodríguez-Soto, 2025; Saénz-Segura et al., 2024; Vorobeva et al., 2021). These are technical modifications propelled by new technologies or by the integration of existing ones. Within this category are the optimization of productive processes, intelligent farms (Vorobeva et al., 2021), real-time information systems (Klerkx et al., 2019), precision application of substances or irrigation (Rodríguez-Soto, 2025), hydrometeorological risk management (Saénz-Segura et al., 2024), etc. This category is commonly known as precision agriculture (Klerkx et al., 2019).

The second one refers to mutations in the distribution and coordination mechanisms between consumption and production that reshape the value systems (Klerkx et al., 2019; Kuzmich, 2021; Rodríguez-Soto, 2025; Saénz-Segura et al., 2024). Here, we can find technologies, apps, and platforms that enable new spaces of interaction for consumers and producers (Klerkx et al., 2019; Rodríguez-Soto, 2025; Saénz-Segura et al., 2024). This is a heterogeneous category; it includes the use of existing communication or payment technologies to the applications developed specifically for the sector or a particular stakeholder.

The first group of innovations has a great potential to increase the environmental sustainability of the sector without sacrificing productivity but can be exclusionary because some technologies are too expensive (Rodríguez-Soto, 2025). For example, information systems permit a better understanding of the needs of each parcel, which can be combined with the precision systems to optimize the application of chemicals and water use. Therefore, reducing the ecological impacts of agriculture while optimizing its productivity. The positive impacts can go further if integrated with other solutions, like bio-inputs or bioeconomy strategies (Rodríguez-Soto, 2025; Saénz-Segura et al., 2024).

The second type improves the economic results and value capture of stakeholders, as it brings closer the consumption and production stages of the value chain, but their applicability depends on the initiative and digital competencies of each user (Rodríguez-Soto, 2025). These contribute to solve a huge issue for the sector: the power asymmetries in the market structures of agri-food value chains (Jiménez, 2011; Qaim & Parlasca, 2025). In these value chains, it's typical to find monopsony markets in the production-distribution stage and monopolistic competition markets in the distribution-consumption stage. This creates feedback loops where power creates wealth and wealth creates power in favour of the middle links of the value chain. Digital technologies enable direct contact between consumers and producers, reducing the margins of the distribution and processing phases (Klerkx et al., 2019; Rodríguez-Soto, 2025; Saénz-Segura et al., 2024).

Another major impact of innovations enabled by digital technologies in the agricultural sector and rural territories is in the knowledge and measurement of ecosystem services (Rodríguez-Soto, 2025). The main economic activities of rural territories are tourism, ecosystem services, and the agricultural sector (French, 2022). But all of these are, in essence, ecosystem services. Tourism is often related to scenic beauty or biodiversity, agricultural production is biomass creation, and it produces other ecosystem services like carbon fixation and biological corridors (Hernández, 2020). Digital technologies can measure these contributions of agriculture and rural territories to society, with inherent potential to transform the urban-rural dynamics.

3. Materials and Methods

This research is exploratory and qualitative. It's designed as a multiple-integrated case study following Yin (2003), aimed at covering the digitalization of agriculture in Costa Rica. This approach is deemed to be a good fit due to the breadth of the objectives and because, to cover the country case, it's necessary to amalgamate several methods. Case studies enable to combine methods and sources of information consistently; what's more, these combinations strengthen its generalization capacities (Yazan, 2015; Yin, 2003). For this paper, three methods were used: the explanatory method of design of public policy (Fontaine, 2015; Rodríguez-Soto & Sáenz-Segura, 2025; Saénz-Segura et al., 2024), in-depth semi-structured interviews (Hernández-Sampieri et al., 2014; Schettini & Cortazzo, 2015), and secondary information analysis and systematization. Figure 1 presents the research design.

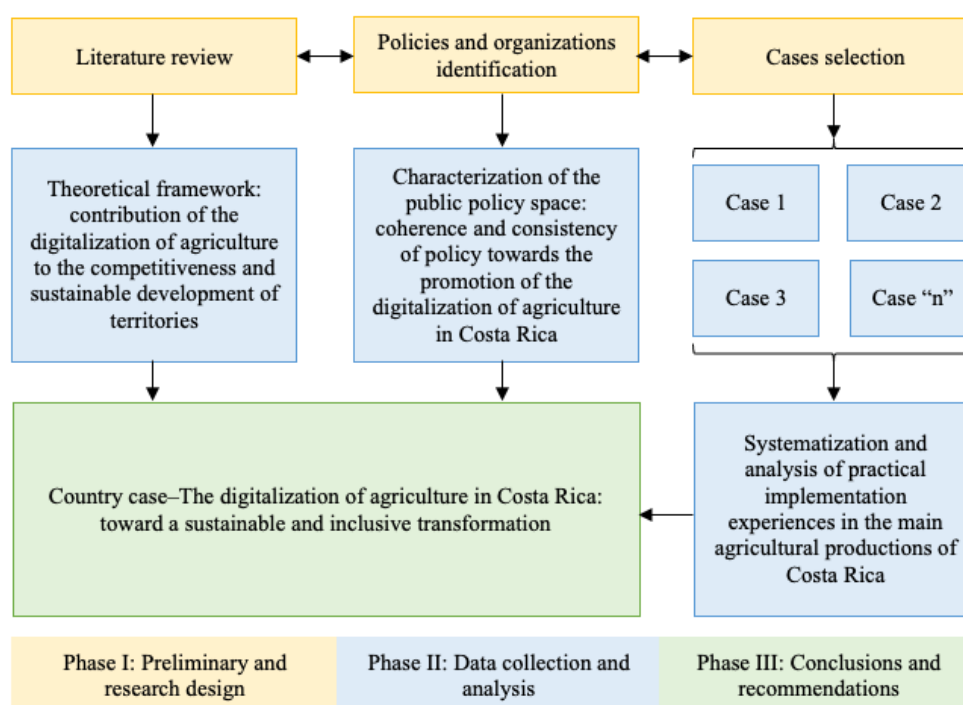


Figure 1. Research design

Source: own elaboration

For the literature review, over 50 papers, books, and chapters were selected; only peer-reviewed sources were considered. They were found using academic search engines and databases (Google Scholar, Scopus, Emerald, ProQuest, Web of Science) with the keywords “digitalisation/digitalization of agriculture”, “digital agriculture”, “agricultural innovation”, “rural innovation”, individually and combined with “sustainable development” and “sustainability”. The selection of papers was carried out by a read of their abstracts, and the chosen ones were processed by a complete read of them and a manual codification. With this, the theoretical framework was built.

For the characterization of the public policy space, the first step was to identify if there was a public policy for the digitalization of agriculture and which public organizations were involved in it. Then each of them was checked to see if they had active policy tools. Once the policy tools were identified, the explanatory method of design of public policy was applied. This method is composed of two analyses: one of coherence and another of consistency.

The coherence analysis decomposes the policy tools into their resources to achieve public action and examine if these resources are in line with their objective. The resources can be classified into four categories: information, organization, treasure, and authority. The information ones are those that distribute or create information and knowledge. Organizational resources are the organizational capabilities and the agencies that manage and implement the policy. The treasury resources are the funds to carry out the policy, for the public agencies or policy users. Authority resources are related to regulation, mandates, or rules.

The consistency analysis evaluates the balance between the actions aimed toward procedural and substantive changes. The procedural dimension of a public policy is composed of the actions that intend

to transform the dynamics of interaction between the state and the policy users. The substantive dimension encompasses all the public actions directed to changing social behaviour. In all, public policies must have resources coherent with their objectives to generate public action and, to achieve this, their instruments must balance procedural and substantive actions consistently.

For the empirical experiences, the cases were chosen taking the agricultural census of 2020 as reference to make sure the results were representative for the country. This census points to four agricultural activities that represent more than 95% of the sector: coffee, bananas, oil palm, and sugarcane. Aside from those, cattle raising was included because 28.5% of the farms in the country are dedicated to it, which is the biggest area dedicated to a single activity (Hernández, 2020).

All the stages of this research were complemented with field visits and in-depth interviews applied to stakeholders, government officials, and experts in the field. A total of 16 interviews were conducted. The initial interviews were carried out based on convenience and the agents' willingness to be interviewed. Subsequently, a snowball sampling methodology was employed, starting with those initial participants. Two interview guides were used—one for policymakers and another for stakeholders—both of which are included in the appendix. The results from interviews, field visits, and secondary information were thematically coded and validated through the triangulation of responses from policymakers, stakeholders, field visits, and the literature; the codebook is also included in the appendix.

This research design combines various qualitative methodologies to provide a comprehensive overview of the state of agricultural digitalization in Costa Rica. As previously noted, it's conceived as an exploratory study aimed at identifying key variables and trends. While it allows for mapping and systematizing the general landscape, its depth is limited; this is simultaneously its strength and its greatest limitation. Consequently, it should be complemented by future research—particularly of quantitative nature—that enables a deeper analysis and measurement of the dynamics identified here.

4. Results

4.1. The public policy for the digitalization of agriculture in Costa Rica

The first thing that stood out was that there isn't a public policy for the digitalization of agriculture in Costa Rica. Despite that, it was possible to identify nine policy tools for the digitalization of agriculture; they're listed in Table 1.

Table 1. Public policy tools for the digitalization of agriculture in Costa Rica

Policy Tool	Description
National Plan of Science, technology, and Innovation (2022-2027)	National scope policy that recognizes the structural difficulties for rural territories and agricultural sector, proposing analysis and procedure changes to tackle them.
Community Labs Network (LINC)	The idea is to create a country-wide network of community labs to foster local innovation and innovative problem solving in different communities (currently in process of implementation).
Research and innovation programs of INTA	Several research and diffusion programs carried out by the National Institute of Agricultural Technology.

Policy Tool	Description
PLATICAR platform	Platform for communication and knowledge distribution for various actors of the sector (producers, researchers, extensionists, etc.).
Public policy for the agricultural sector of Costa Rica 2023-2032	Creation of digital capacities in the policy users and civil servants to ease procedures; it includes other proposals without clear resources.
Microcredit program	Microcredit program (max. \$35 000) with a bias toward innovative solutions in dairy production.
Plan for Digitalization MIPYME 2019-2022	Public-private international partnership sponsored by the Organization of American States, Google, and Kolau, to help small stakeholders take their business to the web.
Green Growth Program	This is a two phases action plan, combining access to capital or financial mechanisms and specialized support for agricultural products with potential in foreign markets.
Discover platform	Inter-institutional cooperation platform to identify windows of opportunity in foreign markets and ease procedures.

Source: Own elaboration.

It's worth noting that, even if there isn't an active public policy for the digitalization of agriculture, there used to be a national strategy from 2015-2021, but it didn't have a continuation afterward (personal communication with O. Vega, vice minister of science and technology, June 13, 2024). This is baffling, as organizations like the Inter-American Institute for Cooperation on Agriculture (IICA) thought that the country could have become a centre for the digitalization of agriculture for Central America. Considering only the active policy tools, most of them have resources to promote public action; which isn't a coincidence, only policy actions with resources were analysed in this paper. Many were eliminated from the analysis because they were formulated as objectives without any disclosure on how they were going to be achieved or by what means.

The scouting of the public policy space revealed two main organizations that lead the digitalization of agriculture: the Ministry of Agriculture and Livestock (MAG) and the Ministry of Science, Technology, and Telecommunications (MICITT). This disclosed a central issue: when asking the MICITT, they said that agricultural activities fall under the scope of the MAG (O. Vega, June 13, 2024), and when asking the MAG, they said that technology and innovation are within the responsibilities of MICITT (personal communication, J. Madriz, INTA engineer, June 20, 2024; personal communication, L. Ramírez, INTA engineer, April 5, 2024). Therefore, the mandate regarding policies for the digital transition of agriculture is unclear, and this could explain—or be explained by—the absence of a public policy on the matter.

Aside from these two organizations, other public agencies collaborate in actions and have their own initiatives to promote the digitalization of agriculture, like: the Ministry of Economy, Industry, and Commerce (MEIC), the Costa Rican Foreign Trade Promotion Agency (PROCOTER), the Ministry of Foreign Commerce (COMEX), public universities, and the National Learning Institute (INA). Also, there are several public-private alliances, for example, with productive cooperatives, Google, Kolau, non-governmental organizations, and international organizations.

4.2. Systematization of practical experiences

A brief on the main applications in each of the selected cases is going to be presented in this subsection. Let's begin with coffee production, here the main challenge is the residual biomass, as it represents around 80% of the production (personal communication, J. Porras, director of innovation, CopeTarrzú, March 12, 2024). This has led to a strong focus on bioeconomy solutions to improve the management of residuals (Rodríguez-Soto, 2024, 2025). Despite that, it was possible to find several significant uses of digital technologies, particularly soil sensors, aerial images, controlled applications of substances, platforms for commerce, and risk management-information systems.

For example, a cooperative was facing distress due to a reduction of their harvests. Originally, they thought the cause was the shadow trees, but they couldn't cut them without losing eco-labels and price premiums. So, they implemented a strategy that uses sensors to obtain real-time data on soil composition, combined with artificial intelligence to design parcel-specific inputs. The base for them is the residual biomass of the production, and they even capture the emission from a tractor to be used as an input too (personal communication with J. Ureña & I. Cordero, CoopeDota, July 12, 2024). With this, they recovered the productivity levels and, even more, they duplicate them: they went from one harvest every two years to one a year; while keeping the shadow trees.

For the banana production, it was possible to find a substantial core of innovations enabled by digital technologies. The major problem for this production lies in the intensive use of chemical inputs and pesticides that entails sustainability and public health hazards (personal communication, M. Jara, agronomist with 30+ years working with bananas, July 9, 2024). The main digital innovations for banana were in the application systems, that combine automatic expelling mechanisms and GPS control of the area of application. The use of drones is mentioned, but it seems to be too expensive. Also, a recent regulation makes the substitution of agrochemicals for biodegradable substances mandatory.

In the case of the oil palm, the use of digital technologies is centred in costs management, with some applications with effects on sustainability and productivity. The oil palm requires little intervention once the plant reaches a certain maturity (personal communication, H. Albertazzi, director of the agronomy department of CoopeAgropal, August 26, 2024). One of the main uses of technologies in this production is in the form of aerial images to diagnose the state of the parcels and plants. With them, the producers can identify segments in need of irrigation, sick, or other conditions without having to dispatch teams. At the same time, they can make localized-specific applications of substances using drones; previously, they had to wait until the condition extended to hire a helicopter or plane.

Additionally, there are significant improvements in the ecological footprint of the seedbed stage due to digital innovations (H. Albertazzi, August 26, 2024). For example, the hydrological footprint was reduced by more than 90% with the implementation of controlled irrigation systems and a precise application of agrochemicals enabled by digital technologies. Not to mention that many of chemical inputs have been substituted with bio-inputs.

In the production of sugarcane, there are active efforts to automate certain production stages, especially the harvest. Sugarcane harvesting entails public health risks—particularly kidney disease—because it exposes workers to the sun and dehydration. Additionally, on January 24, 2024, the Ministry of Agriculture and Livestock signed an agreement with LAICA—a major organization dedicated to

sugarcane production in the country—to promote sustainability through innovation. For this case, it wasn't possible to arrange interviews with any actor—despite numerous attempts.

Finally, for the cattle raising, digital technologies are transforming the production in three ways. First, the use of collars and applications to maintain better control over livestock and develop information systems that improve decision-making regarding efficiency and sustainability (M. Jara, also has a cattle farm, July 9, 2024; personal communication, G. Orozco, developer of the app InnoBovino, August 22, 2024). These are particularly useful to assist producers to develop regenerative production designs (G. Orozco, August 22, 2024). Secondly, in dairy farming, keeping records of each animal's production, monitoring their health status, and determining when to inseminate them (M. Jara, July 9, 2024). Thirdly, regarding farm management, ensuring greater accountability for costs, profits, and productivity (G. Orozco, August 22, 2024).

5. Discussion

5.1. Analysis of the public policy space for the digitalization of agriculture

From the analysis of the public policy space and actions, it's concluded the policy space is inter-bureaucratic, fragmented, and scattered, coincident with previous research (Rodríguez-Soto, 2024; Saénz-Segura et al., 2024). Despite that, the policy tools analysed were found to be coherent in their means and ends, as almost all of them have a reasonable degree of resources to achieve their objectives. But many others were discarded due to a complete lack of them. Table 2 synthesizes the analysis of the public policy space for the digitalization of agriculture by policy tool and resources.

Many instruments have a heavy bias toward information resources, like the PLATICAR platform, the Discover platform, the Green Growth Plan, the community labs, the research and innovation programs, and the public policy for the agricultural sector. Another major focus is on the authority axis, usually related to easing the procedures for the stakeholders, for example, the public policy for the agricultural sector, the Discover platform, and the Green Growth Plan.

The most coherent policy tools tend to privilege low-cost actions, while the more ambitious ones are often phrased as objectives without a clear disclosure of their resources. Also, there is a huge lack of treasury type actions, which can be explained by the fiscal constraints the government is facing. Yet, one of the biggest obstacles for agricultural innovations is the exclusion from the financial system and the ordeals producers must face to get financial leverage (J. Madriz, INTA engineer, June 20, 2024). In all, the focus on information and authority actions is useful because these are the ones that are viable in the short term. But the lack of treasure type instruments must be addresses in the mid-long term to surpass the structural challenges rural and agricultural stakeholders face.

Table 2. Analysis of the public policy tools for the digitalization of agriculture.

Policy tool	Resources				Dimension of incidence
	Information	Authority	Treasury	Organization	
National Plan of Science, technology, and Innovation (2022-2027)	√	√	X	√	Substantive & procedural
Community Labs Network (LINC)	√	X	√	√	Substantive

Policy tool	Resources				Dimension of incidence
	Information	Authority	Treasury	Organization	
Research and innovation programs of INTA	✓	✓	✓	✓	Substantive
PLATICAR platform	✓	✓	✓	✓	Procedural
Public policy for the agricultural sector of Costa Rica 2023-2032	✓	✓	✓	✓	Procedural
Microcredit program	X	X	✓	✓	Substantive
Plan for Digitalization MIPYME 2019-2022	✓	X	✓	✓	Substantive
Green Growth Program	✓	✓	✓	✓	Substantive
Discover platform	✓	✓	✓	✓	Substantive & procedural

Source: Own elaboration.

Scarcity of resources is half of the issue; the other is the fragmentation of the policy space. Public organizations tend to frame their public actions carefully to not invade the jurisdiction of the others. This contributes to further dilute the scarce resources between multiple public organizations that sometimes even duplicate functions. This can be attributed to the lack of a public policy for the digitalization of agriculture that establishes the scope of action of each organization and coordinates the use of resources. At the same time, this lack of a public policy makes it impossible to carry out the consistency analysis. The consistency of a public policy is analysed by the balance of substantive and procedural components of its public actions in aggregate.

This research reveals the persistence of a long-term weakness of the public sector in Costa Rica: difficulties for inter-institutional articulation (Rodríguez-Soto, 2024; Sáenz-Segura et al., 2024), combined with narrow cooperation and coordination capacities and low budgets. In this line, it's worth noting that the more coherent and successful policy tools are those implemented from a single agency from an intra-bureaucratic scope. This is the case of the Discover platform and the Green Growth Program (from PROCOMER) and the PLATICAR platform (from INTA, the one running for the longest time).

5.2. Digitally empowered innovations on the productive systems

It's possible to discuss the impacts of the different technologies in terms of sustainability, competitiveness, and inclusion. Table 3 synthesizes the findings.

Table 3. Impacts of digital technologies in the sustainability and productivity of agricultural production.

Technology	Impacts	Experiences
Soil sensors	*Create information systems on the soil composition that allow to use inputs specific to the requirements of the parcel, optimizing the use of substances.	*Coffee production. *Oil palm production. *Experimental greenhouses. *Cattle rising.

Technology	Impacts	Experiences
AI input design	*Process information and design inputs with specific compositions to each parcel faster, optimizing the use of substances, in the economic and environmental sense.	*Coffee production. *Experimental greenhouses.
Aerial images	*Diagnose the production faster and without dispatching teams, reducing the economic and environmental costs of supervision.	*Coffee production. *Oil palm production. *Banana production.
Drones	*Localized application of substances and water; cheaper for smaller areas but with a trade-off of cost-sustainability for general use.	*Coffee production. *Oil palm production. *Banana production.
Precision application systems	*Reduce the use of substances, water or chemicals to the optimal amount, improving productivity while reducing ecological impacts.	*Oil palm production. *Experimental greenhouses.
Apps for production	*Foster regenerative designs and an economically efficient management of production.	*Experimental greenhouses. *Cattle rising.

Source: Own elaboration.

The soil sensors have great impacts in terms of sustainability and competitiveness. The most relevant case to illustrate it was the coffee production, but they have been used in seedbeds across other crops. Even if this innovation increased sustainability and productivity, it's not cheap. In many of the cases, it's inclusive because it's being implemented by collective organizations, yet, for small and medium stakeholders on their own it might be prohibitive. This real-time information systems are one of the main characteristics of precision agriculture and their application boosts productivity, as has been noted in previous research (Khan et al., 2021; Klerkx et al., 2019; Vorobeve, et al., 2021), as well as in these cases.

A second digital innovation is the use of aerial images, which allows the stakeholders to check the status of their production fast and without transportation costs. These are being used across the agricultural sector and by the government to map the production and build information systems. They're widely utilized by collaborative organizations, like cooperatives. Cooperatives have agronomy departments and limited resources, with which they must keep up with a lot of stakeholders. Aerial images let them check on the status of their associates' production and give them support quicker.

This is often used in combination with drones. Aerial imagery identifies specific areas, which are treated through precise applications of substances carried out by drones. Drones enable to work in smaller zones, which is impossible—at least harder—with other vehicles, like planes or helicopters. Despite that, drones pose a dilemma in terms of inclusion, they're significantly more expensive to hire; around five times more than a plane and twice as much as a helicopter (estimates per hectare by M. Jara, 9 July 2024). The use of information systems built from soil sensors and aerial images has achieved great improvements in terms of costs and sustainability of the agricultural productions.

These economic challenges and potential aren't new, the potential of the digitalization of agriculture to join economic and sustainability goals and to increase innovation and inequality gaps have been widely discussed in the literature of developing economies; in Latin America (Le Coq et al., 2024; Rodríguez-Soto, 2025; Sáenz-Segura, 2024), Africa (Gavrilova, 2022), and Russia (Kuzmich, 2021; Vorobeve, et al., 2021). The case of Costa Rica shows that the difficulties are being faced with

alternative forms of collective organization. This is a successful strategy with a long history in the country, the collaborative sector has been a main driver of rural development for years (Jimenez, 2011; Rodríguez-Soto, 2024, 2025; Sáenz-Segura, 2024).

Some precise application systems are being tested in greenhouses and seedbeds by a cooperation project of the Ministry of Agriculture and Livestock and South Korea (J. Madriz, June 20, 2024). This project is exploring the viability of Korean smart greenhouses in Costa Rica, with a donation of two by Korea. The greenhouses have several advanced functions, like climate control (temperature, humidity, light, etc.), sensors, remote control, precision application systems, automatic irrigation, and others. These technologies achieved significant reductions of water and agrochemicals use, more than 80%, while keeping the productivity up.

They also make it possible to introduce non-typical crops in the territories, fostering the diversification of production. Despite the advantages, the project has shown that not all these technologies are useful in Costa Rica; for example, the roofs are designed for snow (there is never snow in Costa Rica), and they lack bug traps (a big problem in tropical countries). Another limitation is related to the costs—the greenhouses are too expensive. The ministry is devising applications that are affordable and suited to the country's needs by breaking down their components. These actions, however nascent, are paramount, as structural difficulties in rural areas make public intervention necessary, as the literature highlights (Roberts, et al., 2017; Ulezko, et al., 2019).

Finally, some digital innovations are fostering a better integration of productive systems and ecosystems. This is the case of the apps used to manage regenerative productive designs. These apps need information on the size of the parcel, its characteristics, and the number of animals or plants in them. With this, they inform those in charge when to move animals or crops to other plots, to keep production within the limits of the ecosystems' regenerative capacity. This innovation has been proposed to solve the main criticism of livestock farming and helps to integrate the productive systems to the ecosystems.

The impacts of these digitally empowered innovations in the agricultural production of Costa Rica confirm what's been reported by previous research: the digitalization of agriculture offers paths for sustainable economic development (Klerkx et al., 2019; Rodríguez-Soto, 2025; Saénz-Segura et al., 2024; Vorobeva et al., 2021). In Costa Rica, previous research has found that they've positive economic returns (Okot et al., 2026) and good environmental effects (Rodríguez-Soto, 2025). Not to mention that many of their impacts directly mitigate the negative consequences of the green revolution mentioned in the literature (Chaves, 2019).

However, this conclusion is preliminary, many of these technologies are still in their early stages in the country, which makes all previous research (including this) a short-term analysis. Other issues, related to political economy due to the possible technological dependence (Le Coq et al., 2024) or innovation divides (Rodríguez-Soto, 2025; Saénz-Segura et al., 2024), remain to be evaluated in the long-term.

5.3. Digitally empowered transformations in the value systems

There are several ways in which digital technologies are transforming the creation and distribution of value in Costa Rica. The first, by putting forward economic costs, many producers, especially smaller ones, operate based on financial costs, not the economic ones as these aren't always that evident (G.

Orozco, August 22, 2024). Numerous stakeholders keep their accounts in notebooks without structure (M. Jara, July 9, 2024). To address this, applications are being used to measure and inform people about economic costs, helping them manage their production efficiently.

This is paramount, politicians and younger generations argue that agriculture isn't as profitable as other businesses, and they use this argument to justify its abandonment. But these apps are proving that the issue is that it isn't managed as a regular business (G. Orozco, August 22, 2024). The profitability of digital technologies has already been estimated in the country, and their effects are significant (Okot et al., 2026).

The use of smart management tools has proven to be effective to make agricultural activities profitable (G. Orozco, August 22, 2024), which supports the theoretical propositions (Vorobeve, et al., 2021). However, there are two main challenges to overcome. First, the heterogeneity of management processes and technology adoption (ranging from notebooks to automated systems), which is related to the size of the production (M. Jara, July 9, 2024). Secondly, many stakeholders are reluctant to invest in intangible assets; they prefer physical inputs over digital tools, a preference correlated to the educational levels (G. Orozco, August 22, 2024). These dynamics reveal that the same structural issues that appear in many regions of the world are present in Costa Rica (Gavrilova, 2022; Kuzmich, 2021; Rodríguez-Soto, 2025; Sáenz-Segura, 2024; Vorobeve, et al., 2021).

The obvious application of digital technologies in the value systems is those that bring closer the consumption and production. These innovations are key to the agricultural sector, which has always faced challenges related to market structures and value chain governance (Jiménez, 2011; Qaim & Parlasca, 2025; Rodríguez-Soto, 2024, 2025; Saénz-Segura et al., 2024). Digital platforms enable the interaction between small, medium, and large producers and consumers. This is particularly useful for smaller stakeholders, who are often at a disadvantage when negotiating with larger companies. They can sell their products on social media and coordinate delivery and payment using existing apps, while larger companies can develop their own apps or websites.

It is an inclusive solution, as it can be developed using existing technologies (low-cost option) or professionally (high-cost option). In both cases, they reduce the power of the middle links of the value chain, improving the outcomes for producers and lowering the prices for consumers. At the same time, this enables another strategy: shifting from commodity markets to premium markets. Stakeholders are opting for smaller production batches aimed at luxury markets with premium prices, rather than mass production at commodity prices. This entails a complete transformation of the productive process, which generally includes environmental and best social practices, utmost care, advanced technical combinations, and the verification of each.

The key to this lies in the networks and advertising enabled by the digital society, which places knowledge within the reach of producers while simultaneously generating demand for better products. Here again, alternative forms of governance have played a huge role, allowing small stakeholders to join their resources to comply with best practices and verification processes. It has been identified that this strategy enables the achievement of economies of scale in ecological labelling (Jiménez, 2011); it appears that the same type of phenomenon is occurring in the face of the digital revolution.

Finally, Procomer's policy instruments are transforming the value system in Costa Rica, representing an interesting case of public initiative. The Discover platform identifies green windows of opportunity for

agricultural products in foreign markets; subsequently, the Green Growth Plan offers credit and technical assistance to capitalize on them. Taken together, this drives stakeholders to upgrade in the value chains and improve value capture following sustainable pathways. This is of paramount importance for rural development, given that one of the main challenges for agricultural production in Costa Rica is the instability of domestic prices (Rodríguez-Soto, 2024). And obtaining better and more stable prices help the stakeholders to access credit, innovate, and continue upgrading.

This initiative must be studied in the long run. Previous research has already identified the potential of digital technologies to improve the coordination between supply and demand to create more efficient agri-food systems (Klerkx, et al., 2019; Kuzmich, 2021). Nevertheless, the use of digital technologies to create windows of opportunity and improvement within value chains has not been explored as a public initiative to foster rural development. This highlights a research gap regarding the digitalization of agriculture and development policy, as current studies tend to focus on private initiatives.

6. Conclusions

It was possible to find several transformations enabled by digital technologies in the agri-food value chains in Costa Rica. A common fact was that many of the innovations stemmed from recurrent or long-term problems of each production, which is coincident with the literature on innovation. Another major trend was the role of alternative governance forms in the diffusion and democratization of innovations and the use of technologies, mostly in the form of collaborative organizations or networks of stakeholders.

In the productive systems, the digital technologies improved the productivity—even doubling it in one case—and sustainability together. This was achieved by a combination of technologies and innovations. On-time diagnoses and precision applications of substances allowed to build better and real-time information systems to improve decision-making processes. This enhanced the sustainability of production, for example, by reducing the hydrological footprint (-90% in one case), the need for agrochemicals (-80% in greenhouses), minimizing the dragging effects of aerial applications of substances, and others.

These precision technologies and information systems might be able to measure the contribution of agriculture and rural territories in terms of ecosystem services. This could become an axis to transform the urban-rural dynamics towards more equitable development through public policy. Current digital technologies can make the significant environmental contribution of the sector and rural areas visible and quantifiable; assigning economic value to this contribution could drive rural development. Costa Rica has a long track record in payments for ecosystem services, making it an excellent testing ground for such a policy.

In the value system, some applications are improving the management decisions of stakeholders by moving their focus from financial costs to economic costs. Likewise, the web and public platforms are used to identify windows of opportunity that enable entrepreneurs to capture value and upgrade in the value chains; public policies support both aspects. Third, commerce through the internet is reshaping the power relations in the agri-food value chains. This is happening because many entrepreneurs are shifting from commodity markets to luxury markets with smaller batches of high-quality production.

Despite the positive effects, some issues and risks in terms of inclusion persist. Many of the technologies being implemented are expensive, whilst agricultural producers face severe difficulties accessing credit. The financial system typically views them as “high-risk” individuals, due to the variability and seasonality of their income; this situation calls for public intervention, given the lack of instruments providing funds or credit to them. In this line, collaborative governance organizations are successful in promoting equitable implementations and access to advanced technologies and funds. However, for actors lacking access to capital or established organizational capabilities, it’s a huge challenge—one that could be exacerbated by structural gaps, while simultaneously deepening them.

Another risk to consider is the dependence on external suppliers of technologies. Many of the technologies analysed are acquired from international suppliers; some even entail long-term relationships due to the compatibility of inputs, spare parts, and repairs. It’s worth noting that an expert from the Ministry of Agriculture and Livestock stated that many technologies and components can be produced within the country. To this end, it is necessary to coordinate the actions of multiple public and private actors: the government, universities, and the private sector.

All of which leads to an issue: Costa Rica needs a public policy for the digitalization of agriculture to materialize its potential. The lack of a public policy led to a fragmented policy space, where the agencies have trouble determining their responsibilities and room for action. Which reflects on modest initiatives that in some cases are redundant. The country has the capacity to carry out a sustainable and inclusive digital transition in the agricultural sector, but this requires coordination among actors. A policy of this kind needs to make financial resources available to stakeholders, synchronize different sectors (academia, private enterprise, and the State), establish and coordinate actions of different public agencies, and address structural challenges (connectivity, energy, and education). Furthermore, a national plan signals the government's commitment, which can attract international funding opportunities and private investment.

In the future, this research could benefit from a quantitative analysis to draw statistical generalizations and to measure the impacts and variables identified here. This would allow more precise policy recommendations.

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7. References

- Benavente, J. M., & Grazzi, M. (2017). Políticas públicas para la creatividad y la innovación: Impulsando la economía naranja en América Latina y el Caribe. Washington, DC: BID. <https://publications.iadb.org/publications/spanish/document/Pol%C3%ADticas-p%C3%BAblicaspara-la-creatividad-y-la-innovaci%C3%B3n-Impulsando-la-econom%C3%ADa-naranja-en-Am%C3%A9rica-Latinay-el-Caribe.pdf>.
- Chávez L. (2019). Desarrollo sustentable: concepto, interpretaciones y su evaluación en el ámbito rural. Estudios rurales en México, 113. <https://www.torrossa.com/en/resources/an/5466800#page=113>
- Fontaine, G. (2015). El análisis de políticas públicas: Conceptos, teorías y métodos. Barcelona: Anthropos Editorial: FLACSO Ecuador.

- French, C. (2022). Rural Innovation Redefined. In Building Rural Community Resilience Through Innovation and Entrepreneurship (pp. 1-16). Routledge.
<https://www.taylorfrancis.com/chapters/edit/10.4324/9781003178552-1/rural-innovation-redefined-charlie-french>
- Gavrilova, N. G. (2022, February). Impediments to the digitalization of agriculture in Africa. In IOP Conference Series: Earth and Environmental Science (Vol. 981, No. 3, p. 032014). IOP Publishing. 10.1088/1755-1315/981/3/032014
- Goulet, F., Schmitt, C. J., Sabourin, E., Le Coq, J. F., & Sotomayor, O. (2019). Sistemas y políticas de innovación para el sector agropecuario: elementos de introducción. <https://hal.science/hal-02846571/>
- Giuntoli, J., OLIVER, T., KALLIS, G., Ramcilovic-Suominen, S., & Monbiot, G. (2023). Exploring new visions for a sustainable bioeconomy. Publication Office of the European Union, Luxembourg.
<https://jukuri.luke.fi/handle/10024/553309>
- Hernández, M. (2020). Modelo general de un nuevo pago de servicios ecosistémicos para Costa Rica. Capital Natural BIOFIN-Costa Rica. https://biofin.cr/wp-content/uploads/2021/11/undp_cr_PAGO_SERVICIOS_ECOSITEMICOS_21-1.pdf
- Hernández-Sampieri, R., Fernández, C., & Baptista, P. (2014). Metodología de la investigación.
- IICA. (2023). Informe de situación y perspectivas de la bioeconomía en América Latina y el Caribe. <https://hdl.handle.net/11324/22104>
- Jiménez, G. (2011). Sustainable upgrading of smallholders in global agri-food chains. [Tesis doctoral, Universidad de Tübingen]
- Khan, N., Ray, R. L., Sargani, G. R., Ihtisham, M., Khayyam, M., & Ismail, S. (2021). Current progress and future prospects of agriculture technology: Gateway to sustainable agriculture. Sustainability, 13(9), 4883. <https://doi.org/10.3390/su13094883>
- Klerkx, L., Jakku, E., & Labarthe, P. (2019). A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda. NJAS-Wageningen journal of life sciences, 90, 100315. <https://doi.org/10.1016/j.njas.2019.100315>
- Kuzmich, N. P. (2021, March). The impact of digitalization of agriculture on sustainable development of rural territories. In IOP Conference Series: Earth and Environmental Science (Vol. 677, No. 2, p. 022019). IOP Publishing. <https://iopscience.iop.org/article/10.1088/1755-1315/677/2/022019/meta>
- Le Coq, J. F., Goulet, F., Kato, K., Van Loon, J., Bert, F. Martínez, D. (2024). Transición digital y políticas públicas en América Latina: elementos de introducción. <https://www.e-papers.com.br/produto/digital-transition-in-agriculture-and-public-policies-insights-from-latin-america/?v=82a9e4d26595>
- Okot, T., Opio, E. H., & Cruz, Y. S. (2026). Digital technologies in tropical agro-SMEs: Modelling return on investment, efficiency, and socio-environmental co-benefits in Costa Rica. Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS), 127, 113-123. <https://doi.org/10.17170/kobra-2026032612021>
- Qaim, M., & Parlasca, M. C. (2025). Agricultural Economics and the Transformation Toward Sustainable Agri-Food Systems. Agricultural Economics, 56(3), 327-335. <https://doi.org/10.1111/agec.70023>
- Ravallion, M. (2015). The economics of poverty: History, measurement, and policy. Oxford University Press.
- Roberts, E., Anderson, B. A., Skerratt, S., & Farrington, J. (2017). A review of the rural-digital policy agenda from a community resilience perspective. Journal of Rural Studies, 54, 372-385. <https://doi.org/10.1016/j.jrurstud.2016.03.001>

- Rodríguez-Soto, J. A. (2024). Digitalización en el sector agropecuario y desarrollo sostenible e inclusivo: Experiencias en Costa Rica. [Master's thesis, National University of Costa Rica]. <https://repositorio.una.ac.cr/items/9ebb20ee-40f7-45ae-a251-52450a72fc68>
- Rodríguez-Soto, J. A. (2025). Agricultural innovation as a determinant of a sustainable transition in rural territories: Evidence from Costa Rica. *Journal of Sustainable Development*, vol.18, No.1. <https://doi.org/10.5539/jsd.v18n1p77>
- Rodríguez-Soto, J. A., & Sáenz-Segura, F. (2025). Una propuesta de abordaje teórico-metodológico al análisis de la transformación digital sostenible e inclusiva del sector agropecuario en Costa Rica. <https://repositorio.una.ac.cr/items/8c6bfa6f-93be-44ea-bff5-e0f1ada782b7>
- Rolandi, S., Brunori, G., Bacco, M., & Scotti, I. (2021). The digitalization of agriculture and rural areas: Towards a taxonomy of the impacts. *Sustainability*, 13(9), 5172. <https://doi.org/10.3390/su13095172>
- Sáenz Segura, F. et al. (2024). Characterization of the Public Policy Space for the Digital Agriculture in Costa Rica: an Analysis from the Instruments. <https://www.e-papers.com.br/produto/digital-transition-in-agriculture-and-public-policies-insights-from-latin-america/?v=82a9e4d26595>
- Schettini, P., & Cortazzo, I. (2015). Análisis de datos cualitativos en la investigación social. Editorial de la Universidad Nacional de La Plata (EDULP).
- Secretaría Ejecutiva de Planificación Sectorial Agropecuaria (SEPSA). (2022). Desempeño del Sector Agropecuario. 2022. http://www.sepsa.go.cr/docs/2023-005-Desempenno_SectorAgro_2022.pdf
- Ulezko, A., Reimer, V., & Ulezko, O. (2019, May). Theoretical and methodological aspects of digitalization in agriculture. In IOP conference series: earth and environmental science (Vol. 274, No. 1, p. 012062). IOP Publishing. <https://iopscience.iop.org/article/10.1088/1755-1315/274/1/012062/meta>
- Vorobeva, E. S., Goncharova, N. Z., Kovaleva, A. E., & Vorobev, O. V. (2021, March). Digitalization of agriculture in Russia: a regional aspect. In IOP Conference Series: Earth and Environmental Science (Vol. 723, No. 3, p. 032082). IOP Publishing. <https://iopscience.iop.org/article/10.1088/1755-1315/723/3/032082/meta>
- Yazan, B. (2015). Three approaches to case study methods in education: Yin, Merriam, and Stake. *The qualitative report*, 20(2), 134-152. https://biblioteca.unisced.edu.mz/bitstream/123456789/3279/1/Three%20Approaches%20to%20Case%20Study%20Methods%20in%20Education_%20Yin%20Merriam.pdf
- Yin, R. K. (2003). *Case study research: Design and methods* (Vol. 5). sage.

8. Appendices

8.1. Interview guide for policymakers

(Presentation, introduction, and permission to record the session)

Block 1: Digitalization of agriculture

- i. What do you understand for digitalization of agriculture?
- ii. Do you consider it be transforming the agricultural sector in Costa Rica?
- iii. (If yes) Which? For whom?
- iv. (If yes to ii.) Do you think these effects can be escalated to other territories of economic activities?

Block 2: Policy and policy tools

- i. Would you modify the current policy tools? How?

- ii. Do you think it is necessary to implement additional policy tools to foster the digital transformation of the agricultural sector? Of what type?
- iii. Do you consider there to be any obstacles? How could they be resolved?

8.2. Interview guide for stakeholders

(Presentation, introduction, and permission to record the session)

Block 1: Digitalization of agriculture

- i. What do you understand for digitalization of agriculture?
- ii. Do you consider it be transforming the agricultural sector in Costa Rica?
- iii. (If yes) Which? For whom?
- iv. (If yes to ii.) Do you think these effects can be escalated to other territories of economic activities?

Block 2: Sustainable and inclusive digital transition

- i. Do you use any digital or information technologies in your productive processes or work? (If yes: Which? How? Why? / If no: Why?).
- ii. What potential do you see in the development of those technologies? What potential do they have for the development of other activities?
- iii. Do you think rural youth could benefit from these technologies, or has it been rural youth who have driven the adoption of these technologies?
- iv. (If yes in i.) What prompted you to use these technologies?
- v. (If yes in i.) Can you give examples of how these technologies have changed the way we work and live?
- vi. (If yes in i.) Was it difficult to include these technologies in your activities? (Yes: What obstacles did you face? / No: Did anything help you?)
- vii. Have these experiences been useful in other contexts? (If yes in i.) / Would you consider it useful to explore these technologies? Why? (If no in i.).

Block 3: Policy and policy tools

- i. Are you aware of any policy, project, or program that promotes the digitalization of agriculture?
- ii. Has any public entity participated in or promoted the use of these technologies in your community? (Yes: Which organization? What was your experience with the public sector?)
- iii. How could the use of technologies in the sector be promoted?
- iv. Which technologies do you think are the most accessible? Why?
- v. How do you think the accessibility of these technologies could be increased?

8.3. Coding book for the analysis of the interviews

Code	Subcode	Instruction
1. Digitalization of agriculture	1.1. Productive system technologies	Use for digitally empowered innovations that transform the productive system (categorize by type of technology and impacts in notes).
	1.2. Value system technologies	Use for digitally empowered innovations that transform the value system and interactions (categorize by type of transformation in notes).

	1.3. Others	Specify in notes.
2. Sustainable development	2.1. Soil Erosion	Use for innovations that reduce or mitigate the soil erosion.
	2.2. Hydrological Footprint	Use for innovations that reduce the hydrological footprint.
	2.3. Agrochemical Toxicity	Use for innovations that reduce or mitigate the public health and environmental hazards of agrochemicals.
	2.4. Coupling to Ecosystems	Use for innovations that foster a better integration of productive systems to ecosystems.
	2.5. Others	Specify in notes.
3. Inclusive innovation	3.1. Accessibility	Use for issues related to the complexity of technological innovations.
	3.2. Finance	Use for issues related to the costs of technology.
	3.3. Governance	Use for alternative governance strategies used by stakeholders to enhance absorptive capacity (classify in notes).
	3.4. Public Policy	Use for adoption of innovations prompted by public policy.
	3.5. Others	Specify in notes.