Global Transformations in Smart Agriculture: Emerging Practices and Policies during the 2024–2025 Biennium

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Introduction

Since the early 21st century, agriculture has undergone a digital transformation that is redefining its productive, logistical, and governance processes. This shift has accelerated through the convergence of emerging technologies such as artificial intelligence (AI), the Internet of Things (IoT), geographic information systems (GIS), agricultural robotics, and big data analytics, consolidating what is now known as smart agriculture. This concept refers to the intensive use of digital technologies to increase the efficiency, sustainability, and resilience of agri-food systems in the face of challenges such as climate change, market volatility, and the scarcity of natural resources (FAO, 2022; World Bank, 2023).

The origins of smart agriculture can be traced back to the evolution of precision agriculture—which emerged in the 1990s—and gradually expanded through the integration of remote sensors, wireless connectivity, and advanced automation. Today, the smart agriculture paradigm goes beyond agricultural yield optimization: it incorporates dimensions such as environmental sustainability, digital equity, traceability, algorithmic governance, and automated decision-making (Wolfert et al., 2017; Klerkx et al., 2019). As a result of this evolution, new practices have emerged—such as predictive monitoring, robotic seeding, and digital twins—alongside novel public policies aimed at regulating and incentivizing this technological transition in rural areas (OECD, 2023; ECLAC, 2023).

Within this context, this chapter poses the following research question: How are artificial intelligence, automation, and digital governance being integrated into the agricultural sector during the 2024–2025 biennium, and what lessons can be drawn for public policy design in Latin America? To address this question, the main objective is to comparatively analyse the adoption of smart technologies in the agricultural sector across five strategic countries—Colombia, Brazil, Germany, Japan, and Australia—by identifying patterns in the implementation of emerging practices and the development of adaptive public policies that promote sustainability and competitiveness in the agri-food sector.

From a conceptual standpoint, emerging practices are understood as actions, tools, or processes that arise in response to technological, social, or environmental transformations and are not yet fully institutionalized but reflect innovative trends within agricultural systems (Rotz et al., 2019). Emerging policies, in turn, refer to regulatory frameworks, incentives, or public strategies still in design or pilot phases, aimed at accompanying technological change in contexts characterized by uncertainty and rapid innovation (JRC, 2022).

The scientific contribution of this chapter is articulated across three dimensions. First, it offers an updated synthesis of the most relevant developments in smart agriculture from a comparative and multi-regional perspective. Second, it identifies best practices in technological governance within rural contexts that have successfully integrated public, private, and academic sectors to scale digital transformation processes in an inclusive and sustainable manner. Third, it presents evidence-based recommendations for strengthening public policy in Latin America, especially in countries such as Colombia, where persistent gaps in connectivity, technical capacity, and regulatory frameworks continue to hinder the effective adoption of smart technologies (García & Martínez, 2023; AGROSAVIA, 2023).

This chapter argues that smart agriculture should not be viewed solely as a technological solution, but rather as an integrated strategy for rural development that demands ethical, inclusive, and context-sensitive governance frameworks. The conclusions assert that the success of its implementation will depend not only on investments in digital infrastructure but also on institutional strengthening, equitable regulation of agri-food data, and targeted technical support for small and medium-scale rural producers.

The review focused on developments between 2020 and 2025, emphasizing the adoption of artificial intelligence, automation, and digital governance across five strategically selected countries: Colombia, Brazil, Germany, Japan, and Australia. The selection criteria prioritized peer-reviewed journal articles, institutional reports, public policy documents, and digital transformation strategies issued by multilateral organizations, national ministries, and research institutions.

Data were gathered from a robust and diverse range of sources. Core scientific databases included Scopus, Web of Science, ScienceDirect, and SpringerLink. Complementary data were drawn from leading international institutions such as the Food and Agriculture Organization (FAO), the Organisation for Economic Co-operation and Development (OECD), the Economic Commission for Latin America and the Caribbean (ECLAC), the World Bank, and the Inter-American Development Bank (IDB). At the national level, additional sources included reports and strategic papers from ministries of agriculture and technology, AGROSAVIA (Colombia), the Joint Research Centre (JRC) of the European Commission, and various observatories on digital agriculture. In total, 91 documents were systematically reviewed, including 45 peer-reviewed scientific articles, 29 technical and policy reports, and 17 national strategy documents on agricultural digital transformation.

To enrich the documentary analysis and validate the emerging findings, twelve semi-structured expert interviews were conducted. Participants were selected using purposive sampling based on thematic expertise, sectoral representation, and international experience. The interviewees included four researchers specializing in agrotechnology and digital transformation, three public officials from ministries or regulatory bodies, three representatives from AgTech startups and technology consortia, and two leaders of producer associations with first-hand experience in digital adoption.

Interviews followed a structured protocol and addressed critical topics such as artificial intelligence deployment in agriculture, barriers to automation, frameworks for digital governance, and ethical concerns regarding data ownership and use.

Analytical Categories

The analysis was structured around three core thematic axes. The first addressed sensor-based agriculture and the Internet of Things (IoT), including the adoption of environmental sensors, satellite monitoring systems, and data-driven agronomic management tools. The second focused on agricultural automation and robotics, such as the use of autonomous machinery, drones, predictive analytics, and algorithmic tools for sowing and harvesting. The third thematic axis examined public policies for digital governance in agriculture, including national strategies, fiscal incentives, regulatory instruments, ICT infrastructure development, and rural digital agendas.

Each axis was analysed through three cross-cutting dimensions: (1) the level of technological implementation, expressed in adoption rates; (2) territorial coverage, with attention to rural–urban disparities and regional patterns; and (3) institutional articulation, referring to the presence, coherence, and effectiveness of governance instruments and policy frameworks.

To systematize and interpret the data, a combination of qualitative analytical tools was applied. These included comparative country-theme matrices to identify policy gaps and good practices; qualitative coding with ATLAS.ti to map regulatory frameworks, co-occurrence of concepts, and thematic trends; and content analysis to assess strategic alignment, discourse consistency, and institutional narratives. Furthermore, two validation workshops were held with research assistants and selected interviewees to refine the emergent categories and ensure internal consistency and interpretive reliability.

The comparative analysis conducted for this chapter reveals differentiated and asymmetric trajectories in the global implementation of smart agriculture during the 2024–2025 biennium. The countries under review—Colombia, Brazil, Germany, Japan, and Australia—exhibited distinct combinations of technological readiness, territorial coverage, and institutional articulation. These findings directly address the research question posed: How are artificial intelligence (AI), automation, and digital governance strategies being integrated into the agricultural sector in Colombia and other technologically advanced economies, and what lessons can be drawn for public policy formulation in Latin American contexts?

Adoption of AI, IoT, and Automation in Agricultural Systems

Technological adoption rates vary significantly between the Global North and Latin America. Germany and Japan have emerged as frontrunners in integrating AI and Internet of Things (IoT) technologies into core agricultural practices. In Germany, approximately 64% of medium and large-scale farms reported using precision sensors, autonomous tractors, and real-time monitoring systems by early 2025, a process facilitated by federal subsidies and the EU's Green Deal digital alignment (BMEL, 2024; JRC, 2022). Similarly, Japan surpassed 70% adoption, driven by demographic imperatives such as an aging rural workforce and institutional mechanisms ensuring algorithmic transparency and ethical data governance (MAFF, 2024, 2025).

Australia followed with 55% integration of IoT technologies, particularly for water management and remote soil diagnostics in New South Wales and Western Australia (OECD, 2023). Its regionally adaptive model, supported by the Digital Farm Grants Program, has enabled medium-scale adoption despite the country's vast rural dispersion.

In contrast, Brazil and Colombia demonstrate fragmented models. Brazil's Agro 4.0 strategy fostered innovation clusters—especially in Mato Grosso and São Paulo—where over 50% of agro-industrial actors deploy automation tools (ECLAC, 2024). Nonetheless, smallholder farmers remain below 20% adoption due to limited extension services and credit access. Colombia's national figure is even lower, with just 18% of rural producers utilizing digital tools by 2025. High-concentration zones such as Antioquia and Cundinamarca contrast starkly with marginal adoption in regions like Cauca, La Guajira, or Putumayo, revealing a dual-speed transformation (AGROSAVIA, 2023; García & Martínez, 2023).

Territorial Coverage and Regional Gaps

The spatial distribution of digital agricultural innovation underscores persistent structural inequalities. In Germany and Japan, the alignment of national broadband agendas with rural inclusion policies has facilitated relatively even technology deployment across territories (MAFF, 2024; BMEL, 2024). These countries exemplify how digital policy frameworks can counterbalance demographic or economic asymmetries.

On the contrary, Colombia and Brazil show agglomerated adoption in export-oriented corridors, while neglected regions remain digitally excluded. In Colombia, rural broadband penetration is below 30%, hindering digital integration even in high-priority agricultural areas (García & Martínez, 2023). Departments such as Tolima and Meta have benefitted from isolated AgTech pilots, yet rural areas affected by conflict and structural poverty continue to lag behind (FAO, 2022). These patterns raise concerns about the potential for digital transformation to reinforce, rather than correct, longstanding territorial disparities.

Public Policy and Digital Governance Instruments

Institutional capacity emerges as a key enabler—or bottleneck—in smart agriculture deployment. Germany and Japan possess consolidated frameworks with cross-ministerial coordination, standardized data infrastructures, and well-defined AI ethical protocols (JRC, 2022; MAFF, 2025). Germany's AgriTech Zukunftspakt harmonizes public-private investment with EU sustainability mandates, ensuring policy consistency. Japan's Smart Agriculture Strategy includes KPIs, smallholder participation incentives, and algorithmic accountability mechanisms.

Australia, despite lacking a unified federal model, benefits from targeted interventions at state level. Its moderate policy maturity, coupled with public-private AgTech consortia, has supported a balanced evolution of digital farming practices (OECD, 2023).

Latin American cases are marked by fragmented policy efforts. Brazil has made notable progress through the Agro 4.0 program and its innovation hubs. However, inter-jurisdictional coordination remains inconsistent, limiting scalability. In Colombia, although AGROSAVIA and MinTIC have advanced in pilot development, the absence of a national smart agriculture law, lack of clarity on data governance, and limited institutional articulation present serious gaps (AGROSAVIA, 2023; World Bank, 2023).

Synthesis of Comparative Patterns

These patterns confirm a central argument of this chapter: technological availability alone does not guarantee inclusive digital transformation in agriculture. Instead, sustainable smart agriculture requires integrated governance, coherent policy instruments, and territorially sensitive strategies. Countries that have embedded digitalization within broader equity and innovation policies are better positioned to lead the transition.

Conclusions

The findings presented in this chapter confirm that the digital transformation of agriculture is neither homogeneous nor exclusively technological in nature. Rather, it constitutes a deeply structural transition shaped by institutional, territorial, and socioeconomic factors. Through the comparative analysis of five countries—Colombia, Brazil, Germany, Japan, and Australia—it becomes evident that the successful adoption of smart agricultural technologies depends less on the availability of digital solutions per se and more on the presence of robust regulatory frameworks, coordinated public policies, and an inclusive vision of rural development. In essence, the country's leading the agri-digital revolution are not necessarily those with the highest technological innovation, but those that have strategically embedded such innovation into national frameworks that are ethical, participatory, and territorially balanced.

In the cases of Germany and Japan, institutional maturity and coherence among agricultural, digital, and territorial policies have been decisive in achieving high levels of adoption of artificial intelligence, automation, and data governance systems. In contrast, in Latin America—and particularly in Colombia—the digital transformation of agriculture is advancing unevenly, concentrated in agro-export regions and leaving vast rural areas behind. This reflects a structural gap between technological innovation and territorial equity, posing a serious risk of reinforcing historical patterns of inequality if not addressed through integrated policy responses.

The chapter also highlights that the deployment of intelligent technologies cannot be decoupled from the development of public policies that guarantee digital rights, adequate infrastructure, and mechanisms for equitable access by small-scale producers. In the absence of such enabling conditions, the implementation of tools such as agricultural sensors, IoT platforms, or predictive algorithms may disproportionately benefit large market actors, thereby perpetuating technological exclusion.

From a scientific standpoint, the central contribution of this research lies in offering a critical, comparative perspective on smart agriculture transformations—moving beyond purely technical or productivity-focused analyses to incorporate political, institutional, and ethical dimensions. By examining issues such as intersectoral coordination, territorial justice, and digital governance frameworks, the chapter broadens the analytical scope of smart agriculture and serves as a valuable input for the design of context-sensitive strategies in emerging economies.

Ultimately, the study concludes that Colombia urgently needs a national smart agriculture strategy that transcends fragmented pilot programs and instead fosters coordinated efforts among ministries, technical institutions such as AGROSAVIA, and territorial stakeholders. This strategy should include clear regulations on data ownership, incentives to facilitate technological adoption by smallholder farmers, and investment in digital infrastructure to guarantee the right to rural connectivity. Only under these conditions can the digitalization of Colombian agriculture become a lever for sustainable development rather than a new driver of exclusion.

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