CAPI
THE CANADIAN AGRI-FOOD POLICY INSTITUTE

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Barriers to Adoption: Digital Agriculture in Ontario's Food Production Landscape

A *Research* Report prepared for CAPI by Kwaku Owusu Twum

Research Report

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The Canadian Agri-Food Policy Institute's mission is to lead policy development, collaborate with partners and advance policy solutions within agriculture and food

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CAPI thanks our group of peer reviewers and the Advisory Committee for their feedback on earlier drafts of this report. The findings, interpretations, and conclusions in this report are solely those of its author.

Note from CAPI

CAPI recognizes the importance of fostering and mentoring the next generation of thought leaders emerging from Doctoral programs across Canada, who are working in multi-disciplinary fields. Through CAPI's Doctoral Fellowship program, CAPI offers a small, innovative group of young students the opportunity to apply their knowledge and expertise to some of agriculture's most critical policy issues.

The fourth cohort of CAPI's Doctoral Fellows (2024-2025) was tasked with focusing their research on policies needed to address pressures on Canada's land base and natural resources arising from agricultural production in the face of climate change, biodiversity loss, global population growth and food security concerns. This paper is the final deliverable of the program, showcasing the interdisciplinary nature of the fellows' research as it relates to the adoption of digital technologies in agriculture in Ontario.

This Fellowship is supported in part by the RBC Foundation through RBC Tech for Nature as part of CAPI's larger environmental initiative, Policies for Land Use, Agriculture and Nature (PLAN).

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Key Takeaways

- **Adoption of Digital Agriculture Technologies (DATs) is uneven across Ontario.** Southern regions lead, while northern and smaller farms lag due to cost and connectivity gaps.
- **Policy fragmentation limits progress.** Misaligned federal and provincial programs create confusion and slow adoption.
- **DATs reduce emissions and improve efficiency.** High-use areas show better environmental outcomes, including lower greenhouse gas emissions.
- **Most farmers are unaware of DAT programs.** Communication and outreach efforts are not reaching key farming communities.
- **Ontario needs a coordinated digital agriculture strategy.** Stronger infrastructure, training, and data governance are essential for climate-smart, inclusive adoption.

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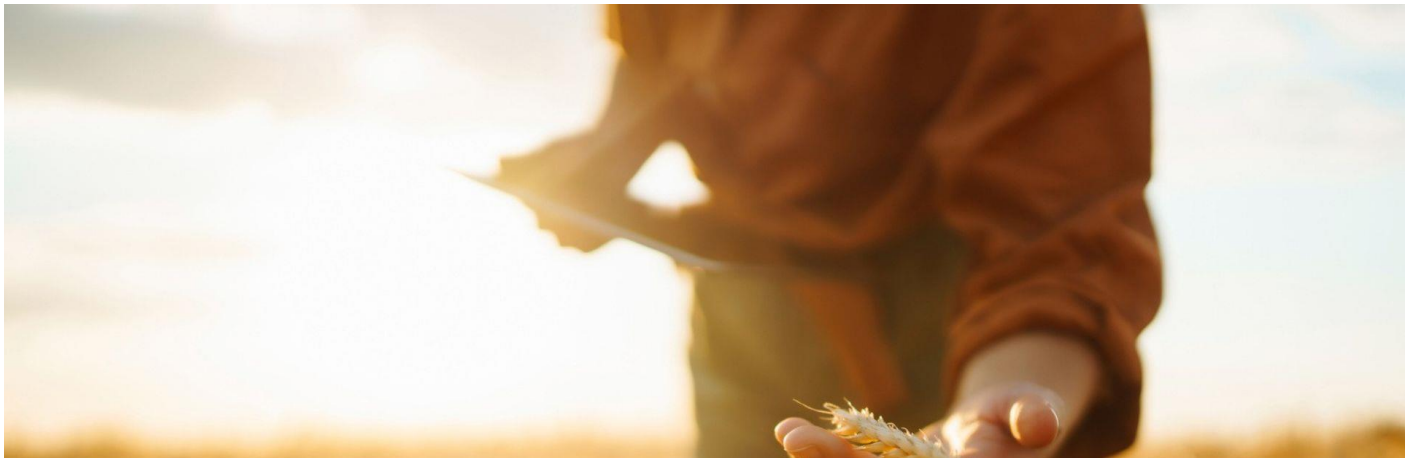
Glossary

AAFC – Agriculture and Agri-Food Canada
CRTC - Canadian Radio-television and Telecommunications Commission
DA – Digital agriculture
DAT - Digital agriculture technologies
GPS - Global Positioning System
GIS - Geographic Information System
PA –Precision agriculture
OFA – Ontario Federation of Agriculture
UAV - Unmanned Aerial Vehicle



1. Introduction

1.1 Context and Rationale

Ontario's farmlands are essential to the province's food supply and economy and play a pivotal role in Canada's agri-food system, supplying a significant share of the nation's produce, grains, and livestock. Yet this agricultural heartland is under mounting strain. Climate change, habitat fragmentation, and urban sprawl—especially around the Greater Golden Horseshoe—are shrinking arable land and threatening long-term environmental sustainability. With less than 5% of Canada's farmland, and much of that concentrated in southern Ontario, farmers face tough choices about how to grow food and remain profitable while protecting soil, water, and biodiversity. Meeting these challenges demands innovative, locally tailored solutions that align agricultural growth with environmental stewardship.

Digital Agriculture (DA) represents a significant shift in modern agricultural practices where data and digital tools are leveraged to enhance decision-making, optimize inputs, and improve sustainability outcomes. Rather than relying solely on manual observation or conventional methods, DA enables farmers to apply precise, real-time interventions tailored to crop and environmental conditions. For this paper, Digital Agriculture Technologies (DATs) are scoped to include GPS-based digital technologies, specifically precision agriculture (PA) tools, Geographic Information Systems (GIS), and Unmanned Aerial Vehicles (UAVs).

These DATs include GPS-guided tractors, drone monitoring, soil sensors, and decision-support applications that help manage farm inputs (water, fertilizer, or crop protection products) more precisely. These tools help farmers make more informed decisions about water use, fertilizer application, and planting schedules—key adaptations in an era of climate uncertainty (Rose et al., 2021)

They can boost crop yields, cut costs, and reduce environmental impacts. But while their value is clear, adoption remains uneven across Ontario. (Balasundram et al., 2023). Farmers in well-connected regions with access to digital infrastructure and financial capital are better positioned to integrate these technologies. In contrast, many small- and medium-sized farms face barriers such as limited broadband access, lack of technical support, and insufficient training. Current policy efforts often focus on economic incentives, such as equipment

grants or tax credits, but they rarely address deeper structural and region-specific research and barriers like digital literacy, farm size disparities, etc. (RBC, 2023; FarmersForum, 2023).

This has led to inconsistent uptake and missed opportunities to scale DATs where they are most needed. Also, while policy discussions increasingly emphasize the role of technology in agriculture, there is a lack of empirical evidence on how DATs contribute to climate adaptation and ecological sustainability in Ontario's food production systems. Without a comprehensive understanding of where and how digital agriculture is being implemented, who benefits, and what barriers persist, the effectiveness of policy interventions remains uncertain.

To address these gaps and ensure digital agriculture becomes a central part of Ontario's climate resilience and food security strategy, policies must move beyond one-size-fits-all approaches. Digital agriculture strategy must be evidence-based and regionally responsive. This includes investing in digital infrastructure, strengthening farmer training and extension services, and developing monitoring systems that capture both agronomic and environmental outcomes. By adopting a more integrated and inclusive policy approach, digital agriculture can serve not only as a tool for enhancing productivity but as a critical enabler of climate resilience and ecological stewardship in Ontario's agri-food sector.

1.2 Research Objectives and Key Questions

This paper investigates how Digital Agriculture Technologies (DATs) are shaping Ontario crop farmers' ability to tackle climate change by identifying where these tools are empowering, where they are falling short, and what's needed to close the gap. Specifically, it seeks to:

- Assess the spatial patterns of DAT adoption and their environmental implications.
- Identify key barriers and opportunities in policy frameworks supporting digital agriculture.
- Provide policy recommendations for enhancing DAT integration into sustainable food systems.

To achieve these objectives, the following key questions will be addressed:

1. Are digital agriculture tools helping Ontario farmers tackle climate change, or creating new barriers?
2. Where are DATs being adopted in Ontario, and how does that shape real-world environmental outcomes?
3. What policy gaps limit DATs' role in sustainable land use and climate change, and where are the biggest opportunities?
4. What targeted strategies can drive smarter, wider adoption of DATs across Ontario's agri-food systems?

1.3 Policy Relevance and Expected Contributions

This research is directly relevant to ongoing discussions on **sustainable land use, agricultural innovation, and climate policy in Ontario**. By analyzing the (in)capacities of digital agriculture through a **spatial, socio-economic, and policy-driven approach**, this policy paper will:

- **Provide empirical insights** on the effectiveness of DATs in addressing environmental challenges.
- **Identify policy gaps and misalignments** that hinder the full potential of digital agriculture.
- **Support evidence-based policymaking**, ensuring that digital agriculture aligns with sustainability and resilience goals.
- **Enhance decision-making among key stakeholders**, including policymakers, agribusiness leaders, and farming communities.

This research assesses the influence of digital agriculture on mitigating pressures on Ontario's farmland and climate through a spatial analysis of DAT adoption and its environmental impacts. The study focuses on Ontario, one of the most urbanized Canadian provinces and a key agricultural hub where digital agriculture adoption has been relatively advanced, yet its environmental impact remains underexplored. Ontario's prominence in Canadian agriculture, combined with its land use pressure, varied climate, makes it an ideal region for examining the spatial distribution and socio-ecological effects of DATs.

By characterizing digital agriculture's role in Ontario's food production landscape, this policy paper will inform more **cohesive, inclusive, and forward-thinking policies** that strengthen the resilience of the province's agricultural sector in the face of climate and ecological challenges.

2. Background

2.1 Canada's Digital Agriculture Landscape

Canada ranks 8th in global agri-food exports, yet places 15th for arable land, with only 4.8% suitable for field crop production (Yildirim et al., 2019; Government of Canada, 2024). A significant portion of this farmland lies in Ontario, placing the province at the heart of national food security and agri-food competitiveness. But this advantage comes with its urban pressure. Ontario's farmers must meet rising productivity demands while reducing climate emissions and protecting soil and water health, especially as urban sprawl and climate instability shrink viable farmland. Navigating these complex trade-offs requires smarter, data-informed decisions. Digital agriculture—through tools like precision farming (leading by 15% of farmers) alongside, remote sensing, and decision support systems—offers promising pathways to boost efficiency and resilience while reducing environmental impacts (Abdulai, 2022; Green et al., 2021; Rose et al., 2021) [See: Figure 1A]. However, Ontario faces distinct adoption barriers, including digital infrastructure gaps, uneven policy support, and a lack of region-specific data. Without targeted, place-based interventions, the province risks falling short of its climate and food security goals.(Abdulai, 2022; Green et al., 2021; Rose et al., 2021).

Despite the national push for digital agriculture, Ontario stands out as a provincial leader in adoption. While Canada's overall uptake of Digital Agriculture Technologies (DATs) remains modest—just 13% of farms use GPS-guided systems—Ontario's field-crop sector tells a different story. Over 78% of field-crop farms in the province employ GPS technology for tracking, guidance, and precision agriculture applications (Government of Canada, 2023; FarmersForum, 2023). This positions Ontario as a frontrunner in harnessing digital tools to improve efficiency and environmental outcomes. Yet, the province still faces gaps in equitable access, infrastructure, and tailored policy support. Despite investments exceeding $3 billion from government and private actors, adoption remains uneven, especially among small- and medium-sized farms (Lemay et al., 2022; Ahuja et al., 2023). If digital agriculture is to reach its full potential—reducing emissions by up to 40% by 2050 and enhancing Ontario's competitiveness—policy must now shift from broad funding to targeted, regionally responsive strategies that close the adoption divide (Abdulai, 2022; Green et al., 2021).

However, whether these DATs support or hinder farmers' capacity to address climate change, particularly from a socio-ecological and geographic context, remains insufficiently explored. Also, research on 'capacities' as a new theoretical lens to examine how local and institutional structures and processes shape the adoption of digital agriculture is limited (Abdulai, 2022; Green et al., 2021; Rose et al., 2021). Furthermore, questions remain unanswered regarding how farmers' knowledge, management strategies, and values regarding DATs and sustainability impact farm-level climate decision outcomes (Hurst & Spiegel, 2023). Previous studies have assessed mainly DA's impacts from a linear, non-spatial context, highlighting its economic outcomes. Hence, exploring the environmental nuances of digital agriculture is imperative.

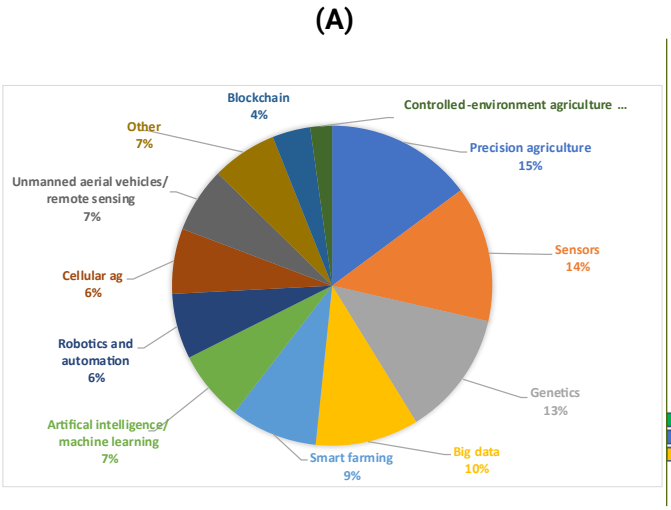
2.2 Key Concepts and Definitions

To understand the role of digital agriculture in addressing climate and challenges, it is essential to clarify several key concepts:

- **Digital Agriculture:** The use of advanced digital technologies integrated into one system to enhance agricultural productivity and sustainability. This paper focuses on GPS-based technologies, specifically precision agriculture (PA) tools, GIS, and UAVs.
- **Capacity:** The ability of individuals, organizations, and systems to plan, implement, and sustain actions that achieve desired outcomes. In the context of digital agriculture, capacity refers to the extent to which farmers possess the necessary resources, knowledge, skills, infrastructure, institutional support, and enabling environments to adopt, adapt, and effectively utilize Digital Agriculture Technologies (DATs). This includes not only technical proficiency but also access to financial capital, digital literacy, trusted advisory networks, and supportive policies that together determine a farmer's ability to integrate DATs into daily decision-making and long-term farm management. [See: Figure 1B]

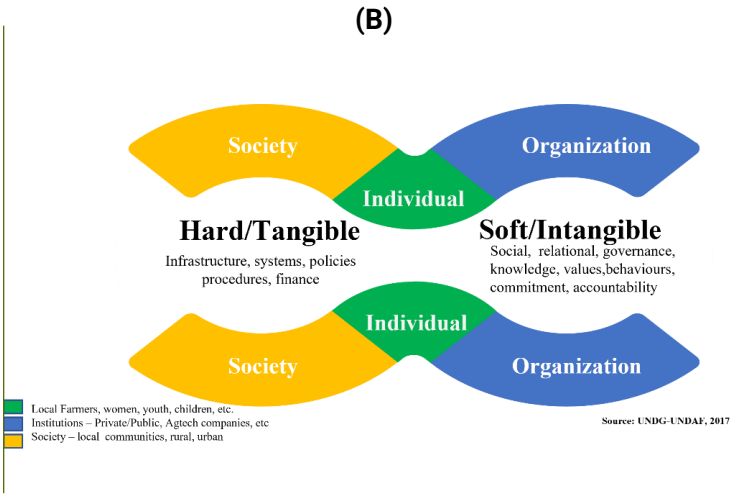
- **Institutions:** Formal organizations responsible for governance, policy implementation, and public service delivery. In this study, institutions include government ministries, agricultural agencies, and research organizations that shape digital agriculture policies.
- **Governance:** The systems and processes that guide decision-making and policy implementation within a social or institutional framework. Governance in digital agriculture includes policy frameworks, regulatory mechanisms, and stakeholder coordination for sustainable DAT adoption.

Figure 0 A



Source: Authors' literature review, 2025, based on (Green et al, 2021; Dibbern et al, 2024).

Figure 1B



Source: UNDG-UNDAF,2014. https: UNDG-UNDAF

3. Literature review

3.1 Understanding Digital Agriculture and Its Role in Ontario's Food Production Landscape

Over the past decade, DAT adoption has increased globally. Ultimately, adoption of these technologies is driven by a need to remain competitive in a global food marketplace. The digitization of agriculture conveys an advantage through a reduction of input costs or streamlining of operations. The environmental benefit is often a secondary attribute that needs to be monetized for the farmer. This is driven by the need for precision farming, data-driven decision-making, and real-time environmental monitoring. Studies highlight that DATs contribute to increased productivity, reduced environmental impact, and better risk management in agriculture (Wolfert et al., 2017; Rose et al., 2021). However, their implementation varies significantly across different regions and farming systems.

In Ontario, the digital shift in agriculture is evident but varied. Larger operations have integrated GPS-guided tractors, drones, and GIS-based planning tools into their production systems (Cairns & Deaton, 2022). In contrast, many small- and medium-sized farms adopt digital tools more selectively, not merely due to cost or infrastructure limitations, but also because certain DATs may not align with their scale, crop type, or labour models (Miller et al., 2023). For example, small fruit and vegetable producers on 20–30 acres may find manual labour more cost-effective than investing in expensive automated systems.

While government programs continue to promote "smart farming" innovations, significant gaps remain in the distribution, utility, and contextual relevance of DATs. Specifically, the spatial dynamics of DAT adoption and its environmental outcomes in Ontario are underexplored, raising concerns about the alignment between digital innovation and the diverse needs of Ontario's farm landscape. Addressing these gaps requires not just more technology, but more non-linear and regionally-responsive strategies that consider the full range of farm sizes, crop systems, and production models.

3.2 Key Trends in Digital Agriculture Adoption

3.2.1 The Global Rise of Precision Agriculture

The integration of real-time data, artificial intelligence, and automation is transforming agriculture globally. Precision agriculture emphasizes data-driven management of crops and soil to reduce waste, enhance efficiency, and increase yields (Gebbers & Adamchuk, 2010). Countries like the Netherlands and Australia lead in this area, with over 70% of farms using tools like precision soil mapping and automated irrigation systems (FAO, 2022). Ontario is beginning to adopt similar technologies in its agricultural sector, particularly in field-crop operations, with 78% of farms already utilizing GPS guidance systems (Government of Canada, 2023).

3.2.2 From Barriers to Enablers: A Policy Lens on Ontario's Digital Agriculture Transition

Canada has demonstrated growing interest in digital agriculture, particularly through government-led initiatives aimed at accelerating smart farming adoption. Programs such as the **Sustainable Canadian Agricultural Partnership (CAP)**, the **Smart Farms Program** under the Vineland Research and Innovation Centre, and **Agriculture and Agri-Food Canada's (AAFC) Agricultural Clean Technology Program** reflect significant national investment in sustainable and technology-driven agriculture. These initiatives provide funding for innovation, environmental sustainability, and precision agriculture tools.

However, despite these efforts, adoption of Digital Agriculture Technologies (DATs) remains uneven across regions, especially in Ontario, due to several persistent barriers:

- **High Cost of Adoption**: Many DATs, such as GPS-guided tractors, variable rate applicators, and Unmanned Aerial Vehicles (UAVs), demand substantial upfront capital. This often places them out of reach for small- and medium-scale producers, who may find limited return on investment for small-acreage operations (Miller et al., 2023).
- **Infrastructure and Connectivity Deficits**: In rural Ontario, broadband and cellular coverage remain inconsistent, limiting real-time data transmission, automated monitoring, and cloud-based decision support systems (Beck et al., 2021). This disconnect constrains full deployment of precision technologies and digital platforms.
- **Knowledge and Skills Gap**: Many farmers lack the digital literacy and tailored training necessary to effectively integrate DATs into their operations. For instance, a lack of region-specific extension services further hinders practical application (Rose et al., 2021).

Despite these barriers, Ontario holds a strategic position to lead the nation's digital agriculture transition. To unlock this potential, policy must shift from generalized investment to targeted, regionally responsive measures. This may include **cost-sharing subsidies for small farms**, **expansion of rural broadband through Ontario's Accelerated High-Speed Internet Program (AHSIP)**, and **enhanced training programs through the Agri-Food Open for E-Business initiative**.

By aligning infrastructure, incentives, and human capacity development, Ontario can transform structural constraints into enablers, positioning its agricultural sector for both climate resilience and global competitiveness.

3.3 Institutional and Governance Considerations in Digital Agriculture

Institutions and governance structures play a crucial role in shaping digital agriculture adoption. Strong institutional support can **bridge the gap between research, policy, and farmer adoption**. However, a **fragmented policy landscape** often leads to **inconsistent regulations, funding gaps, and a lack of stakeholder coordination** (Baur & Roo, 2020).

Key governance challenges in digital agriculture include:

1. **Policy fragmentation:** Overlapping jurisdictions between **federal, provincial, and local governments** result in inconsistent DAT policies. Inconsistent support for Digital Agriculture Technologies (DATs) arises from overlapping mandates and a lack of coordination between federal, provincial, and municipal governments. For example, while Agriculture and Agri-Food Canada funds national innovation programs, provincial initiatives like Ontario's Agri-Tech Innovation Program operate with different eligibility criteria and priorities. This misalignment can confuse farmers and limit the effectiveness of DAT adoption incentives at the farm level.
2. **Regulatory uncertainty:** Farmers in Ontario face persistent concerns regarding data ownership, privacy, and the ethical use of algorithms embedded in DATs. The absence of clear provincial or national standards for agricultural data governance, such as who owns yield data collected by GPS systems or how AI-driven recommendations are generated, creates hesitation around adoption (Bronson & Knezevic, 2016; Ruder, 2023). Without legal frameworks to address intellectual property rights or algorithmic transparency, especially for small and independent farms, trust in digital tools remains low (Rotz et al., 2019).
3. **Limited stakeholder engagement:** In Ontario, digital agriculture innovation is hindered by weak coordination across critical stakeholders—farmers, agri-tech developers, researchers, and policymakers. These groups often work in silos, leading to mismatches between technological design and real farm-level needs (Cairns & Deaton, 2022; Miller et al., 2023). The lack of co-designed pilot programs or regional agri-digital platforms reduces the potential for scalable, context-sensitive innovations, particularly for small and mid-sized farms that operate under different economic and logistical constraints than larger enterprises (Lemay et al., 2022).

   Ontario must develop **a coordinated policy approach that integrates digital agriculture with climate adaptation, conservation, and rural development strategies**. Strengthening institutional capacity, **enhancing governance mechanisms, and fostering multi-stakeholder partnerships** will be key to unlocking DATs' full potential.

3.4 Policy Implications and Research Gaps

While digital agriculture holds promise, significant gaps remain in understanding **its impact on climate resilience, and equitable adoption in Ontario**. Future policies must address:

- **The environmental footprint of DATs**: How do digital tools influence **soil health, water use efficiency, and carbon emissions**?
- **The digital divide in agriculture**: What policies can bridge the **access gap between large agribusinesses and small-scale farmers**?
- **Scalability of DAT initiatives**: How can Policies support **widespread adoption without exacerbating socio-economic inequalities**?

"Digital agriculture technologies have increased crop yields by up to 20% in Ontario's farms for the 2024 growing season." As we step into 2024, the agricultural landscape in Canada, particularly in Ontario, is undergoing a remarkable transformation
– Farmonaut, 2024

4. Methodology

This policy paper adopts a mixed-methods approach grounded in the goal of strengthening Ontario's food production systems while advancing climate change objectives. The study demonstrates how science-based insights can inform smarter, more regionally responsive agricultural decision-making by integrating geospatial mapping, policy evaluation, and institutional analysis. The research is organized around three core components:

1. **Policy and Institutional Review**
   A document analysis is adopted from existing provincial and federal policies to identify structural barriers and enabling conditions affecting the adoption of Digital Agriculture Technologies (DATs). This includes examining how regulatory frameworks, funding programs, and institutional mandates align—or misalign—with the realities of Ontario's diverse farming systems.
2. **Farmer Perspectives via OFA Survey**
   In collaboration with the Ontario Federation of Agriculture (OFA), we conducted an online survey targeting a diverse cross-section of Ontario farmers. This captures ground-level realities—how farmers perceive DATs, their capacities to use them effectively, and how adoption influences climate resilience and decisions on their farms.
3. **Spatial Mapping of DAT Uptake Analysis**
   Using geospatial analysis, we map where and how DATs (e.g., precision agriculture, GPS systems) are used across Ontario's agricultural zones. This allows us to assess whether these technologies contribute to measurable improvements in emission reductions, soil health, and water quality protection—key performance metrics tied to climate adaptation.
4. **Comparative Benchmarking**
   We assess how Ontario's digital agriculture strategies compare to global exemplars—such as the Netherlands, Australia, and USA—that have effectively integrated DATs to boost yields while cutting emissions. By analyzing their regulatory models, incentive structures, and data-sharing frameworks, we identify actionable lessons Ontario can adapt to enhance technology adoption, environmental outcomes, and policy coherence.

4.1 Policy and Institutional Analysis:

Table 4.1. Document analysis table

Documents	Sources	Number (N=32)

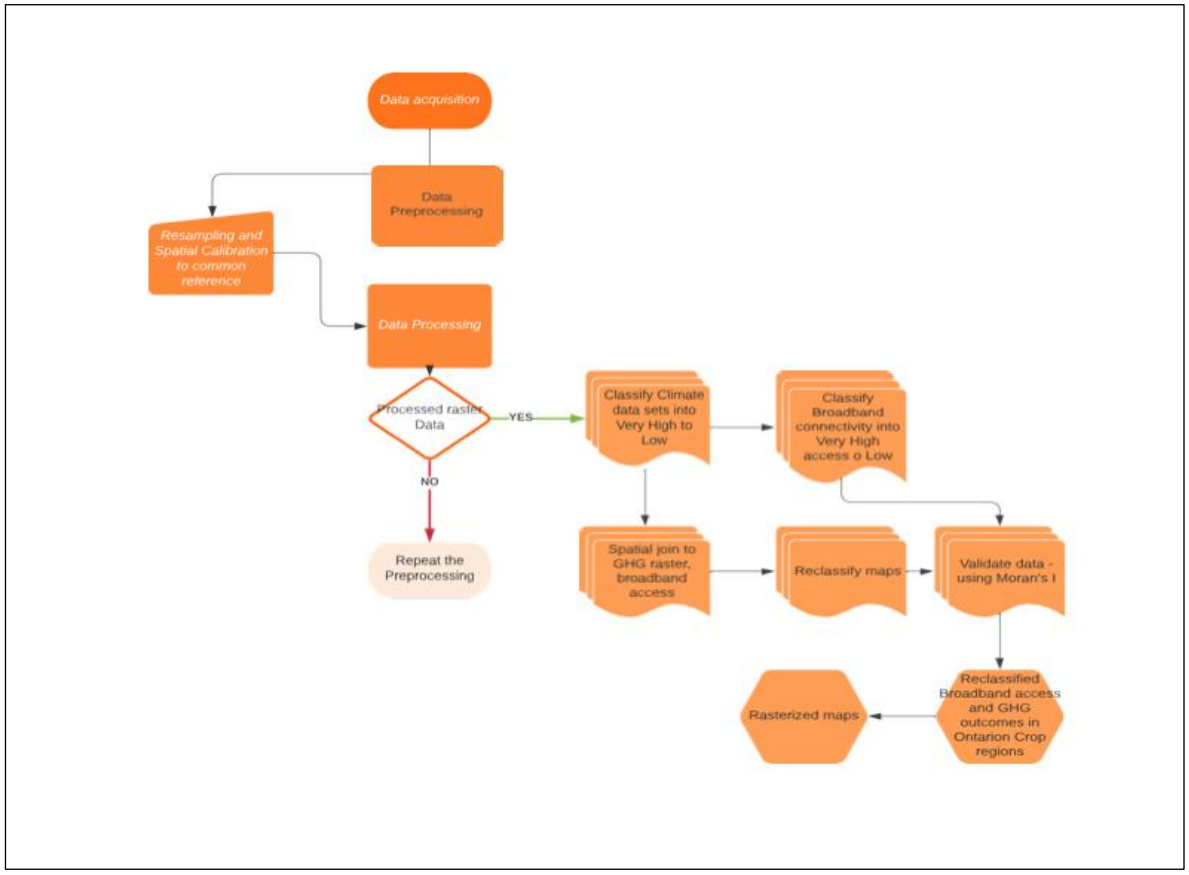
Government and Policy Documents:
• Government of Canada Open Database
• Agriculture and Agri-Food Canada (AAFC)
  ○ Policies & Strategies: Canada's Food Policy, Sustainable Agriculture Strategy
• Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA)
  ○ Programs & Initiatives: Ontario Digital Agri-Food Strategy
	AAFC, OMAFRA, Government of Canada publications:
	Search terms: "Digital Agriculture Ontario," "Precision Farming Policy," "Agricultural Innovation and Climate Change"
		12

Academic and Scientific Research	Scopus: **Search terms:** "Digital Agriculture Ontario," "Precision Farming Policy," "Agricultural Innovation and Climate Change"	8
Industry Reports and Grey Literature: • Consulting & Market Research	McKinsey, Deloitte, RBC	4

• Farmer Networks & Advocacy Groups	Ontario Federation of Agriculture (OFA), Farmers Forum, Canadian Federation of Agriculture (CFA), and Grains Farmers of Ontario (GFO)	
Global Benchmarks (For Comparison): • UN FAO: SAFA Framework and Policy Assessments • European Union & USDA: Digital Agriculture Initiatives For Benchmarking	UN reports EU reports	2

1.1. Spatial Analysis

Figure 2



Source: Author's Construct, 2025

4.2 Data collection overview

Data type and variable	**Source**	**Description**	**Relevance**
Satellite classified imagery of crops in Ontario	Agriculture and Agri-Food Canada	Contains all crop yields in Ontario for 2016 and 2021	Support in scoping ecological outcomes to crop fields
Farmer attitudes, DAT usage, and	Online survey conducted via the	Captures farmer-level data on digital tool usage, decision-making behaviour, barriers to	Provides primary, ground-level insights into how DATs are being used, their effectiveness, and what

perceived barriers	Ontario Federation of Agriculture (OFA)	adoption, and perceived climate and outcomes	support structures farmers need for climate-smart innovation
Broadband connectivity	CRTC	Broadband connectivity measured in pixel/mpbs	Used as a proxy to define and scope DAT adoption areas.
Greenhouse Gas (GHG) Emissions	Government of Canada open data, AAFC	Greenhouse gas emissions data in 2016 and 2021, measured in very high to low	Used as an indicator for assessing the environmental outcome of DATs adoption

5. Results

5.1 Policy and Institutional Gaps in Digital Agriculture Governance

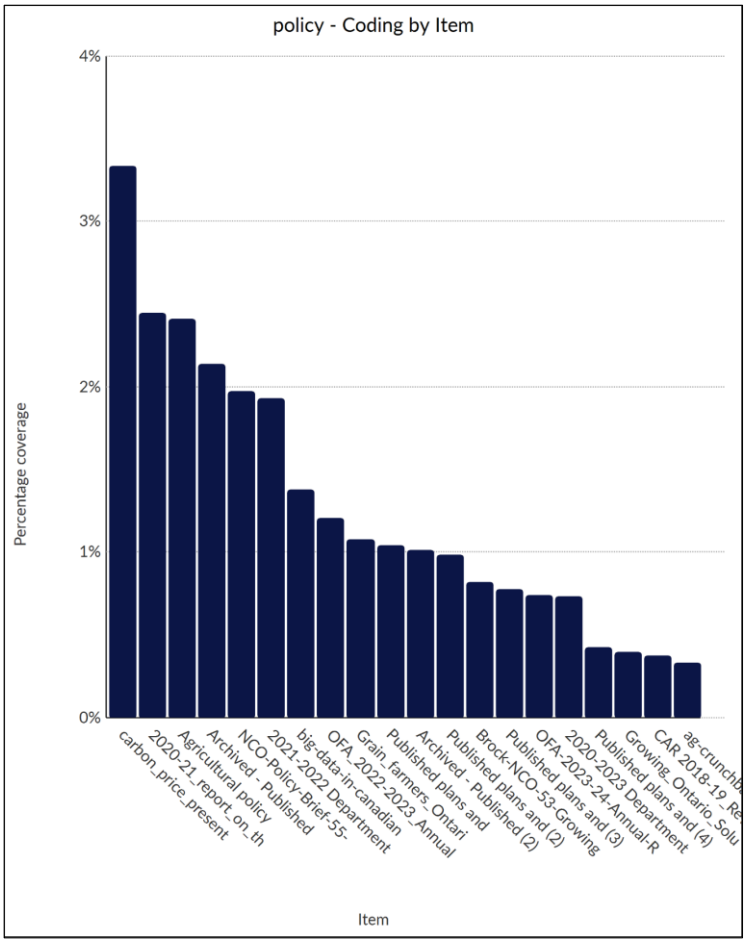
Table 5.1. Relevance to DATs

	High		Medium	Total
Document Policy		**Report**	**Report**	
2016–22 AAFC Departmental Plan		1		1
Agricultural Research Institute of Ontario (ARIO) annual report			10	10
Canada Food Policy	1			1
OMAFRA-U of G Agreement Annual Report 2021/24		2		2
OMAFRA-U of G Agreement Annual Report 2021/25		1		1
OMAFRA-U of G Agreement Annual Report 2021/26		1		1
OMAFRA-U of G Agreement Annual Report 2021/27		1		1
Ontario Federation of Agriculture Annual Report		2		2
Published plans and annual reports		9		9
Standing Policy	1			1
Sustainable Agriculture Strategy	1			1
Sustainable Canadian Agricultural Partnership_ (Sustainable CAP)	1			1
Grand Total	**4**	**17**	**10**	**31**

A review of Ontario's agricultural policies and institutional frameworks identified several barriers to DAT adoption:

1. **Policy Fragmentation:**
    - There is **no unified digital agriculture strategy** aligning technology adoption with climate change goals.
    - Overlapping mandates between **federal and provincial governments** lead to inconsistent support programs.
2. **Financial Barriers:**
    - Current funding mechanisms primarily support **large agribusinesses**, leaving small and mid-sized farms at a disadvantage.
    - **Limited incentives** for adopting DATs in -sensitive regions.
3. **Capacity Constraints:**
    - **Limited number of training programs** for farmers on precision agriculture and GIS-based tools.
    - **Weak extension services** to support knowledge transfer from research institutions to farmers.
4. **Data and Privacy Concerns:**
    - Farmers express reluctance to adopt DATs due to uncertainty over data ownership and regulatory frameworks.
    - Absence of clear policies on farm-level data governance limits trust in digital platforms.

Figure 3



5.2 Comparative Insights: Ontario vs. Leading Global Jurisdictions

A benchmarking analysis comparing Ontario's digital agriculture policies with those of the Netherlands, Australia, and selected U.S. states reveals:

- Ontario lags in coordinated digital agriculture strategies, whereas the Netherlands has a dedicated policy framework integrating precision farming with sustainability goals.
- Financial incentives for DAT adoption in Ontario are fragmented, while Australia provides targeted subsidies to ensure equitable access.
- Ontario has comparatively fewer structured public-private partnerships focused on digital agriculture adoption compared to several U.S. states, where land-grant universities actively collaborate with private sector stakeholders to drive DAT innovation and farmer uptake (Schimmelpfennig, 2016; USDA, 2021). This limited coordination in Ontario constrains the diffusion of context-specific technologies and practical support systems for farmers.

5.3 Spatial Patterns of DATs and Climate change outcomes in Ontario

Figure 4

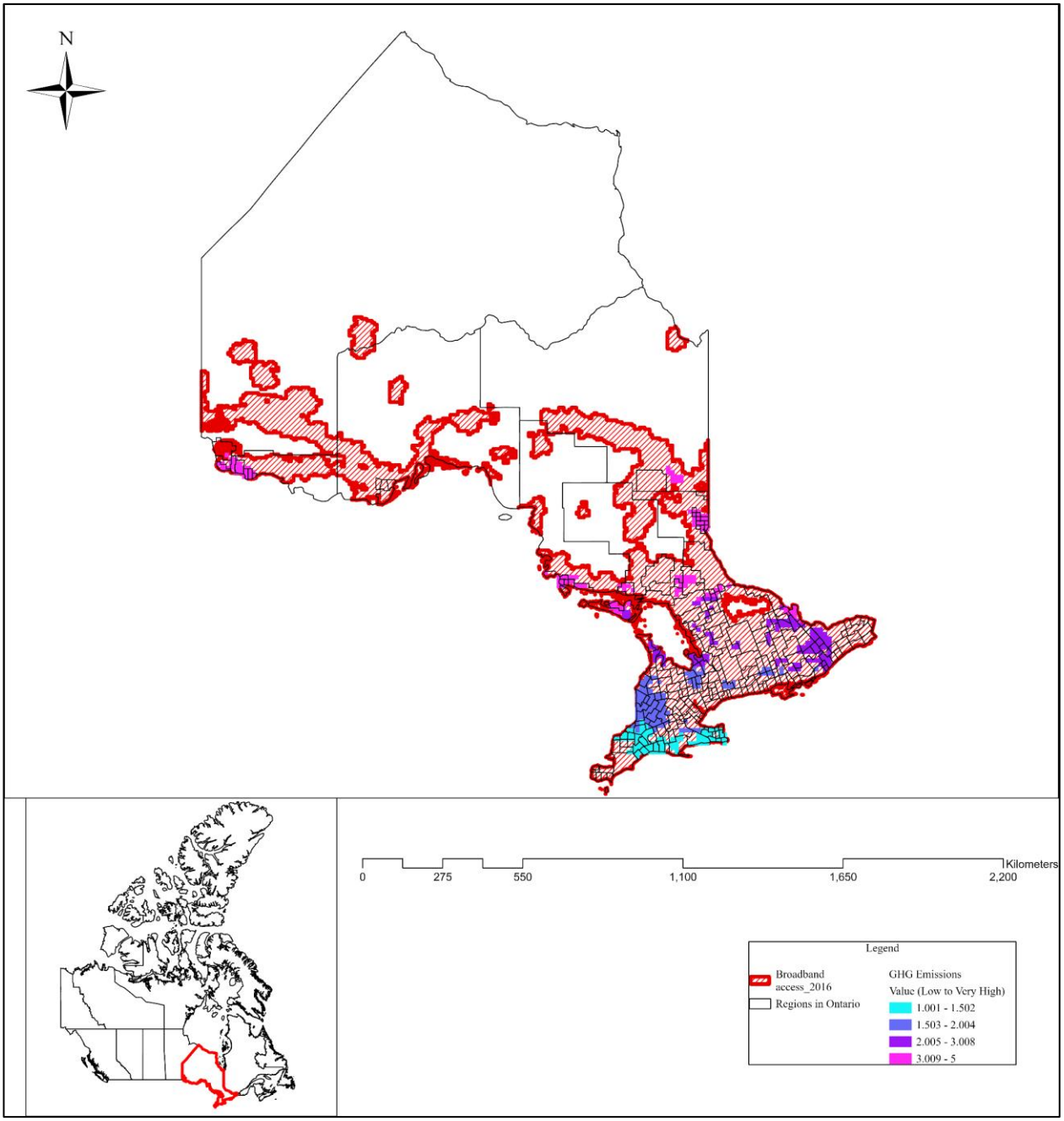


Figure 4: Classified cluster analysis of DAT adoption and GHG outcomes in Ontario using Moran's Spatial Cluster Index

Source: CRTC, 2016; AAFC, 2016

Figure 5

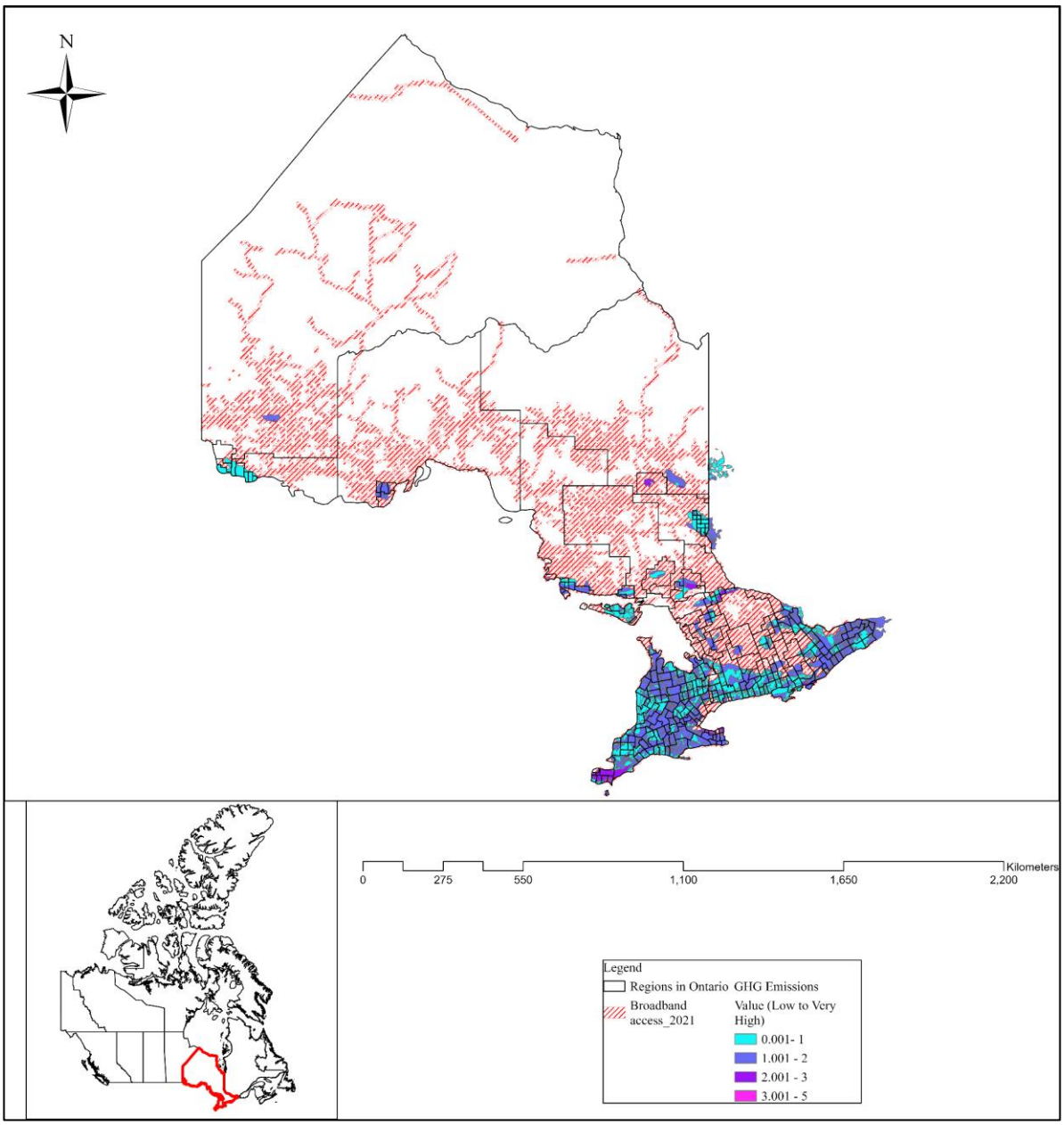


Figure 5: Classified cluster analysis of DAT adoption and GHG outcomes in Ontario using Moran's Spatial Cluster Index

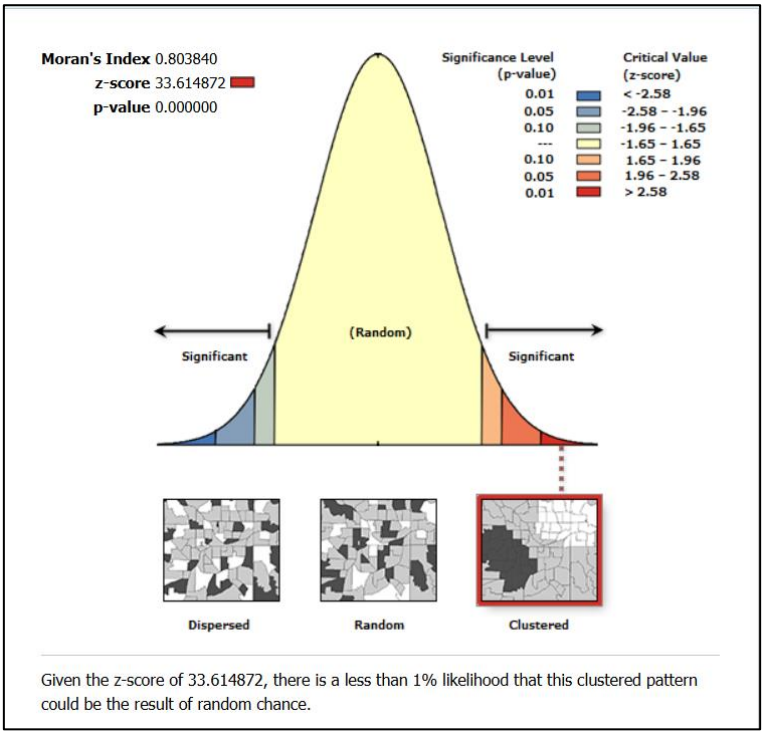
Source: CRTC, 2022; AAFC, 2022

Between 2016 and 2021, the adoption of Digital Agriculture Technologies (DATs) in Ontario accelerated notably in the southern regions but remained limited in the North, highlighting a growing spatial divide in technological integration across the province. This analysis draws on satellite-classified cropland data and broadband connectivity (used as a proxy for digital readiness) to capture temporal and geographic changes in DAT adoption. The five-year period aligns with key infrastructure upgrades and policy interventions aimed at promoting precision agriculture tools such as GPS-guided machinery, UAV field monitoring, and GIS-enabled farm management. By comparing these two time points, the analysis identifies not only where digital agriculture is gaining traction but also where uptake has stalled, shedding light on underlying disparities in access, infrastructure, and enabling conditions. These spatial patterns have important implications for environmental performance, revealing how and

where DATs may be driving improvements in input use efficiency, emissions reduction, and soil health management.

A **Classified Cluster Analysis** using **Moran's Spatial Cluster Index** was conducted to assess the spatial relationship between DAT adoption and GHG outcomes across Ontario's agricultural regions. Notably, the analysis reveals that high-DAT adoption zones—concentrated primarily in southern Ontario—are associated with lower emissions (See Fig. 4 and 5). This reduction is largely driven by practices such as precision fertilizer application, reduced tillage, and the use of GPS-guided machinery. These findings offer a promising opportunity for Ontario's climate policy: the integration of DATs is already yielding measurable environmental benefits and can serve as a scalable model for climate-smart farming.

Figure 6



In contrast, regions with low adoption rates—particularly in northern and eastern Ontario—continue to exhibit higher emissions due to reliance on conventional methods, including excessive chemical inputs and inefficient land-use practices. These spatial disparities underscore the importance of targeted, region-specific strategies to expand DAT adoption. Incentivizing tools such as UAV-based crop monitoring and GIS-driven planning and linking DAT-driven emission reductions to carbon credit markets, can accelerate adoption while aligning Ontario's agricultural sector with its broader climate goals.

Figure 7

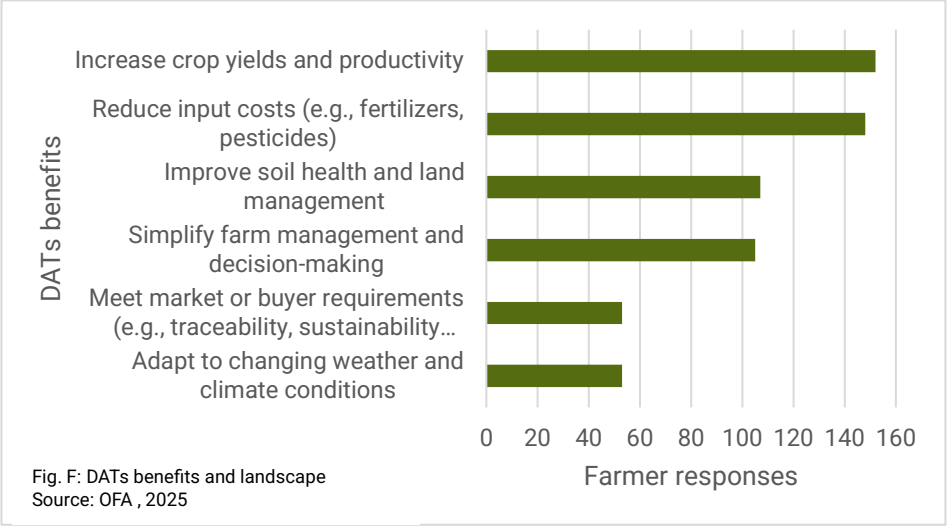


Fig. F: DATs benefits and landscape
Source: OFA , 2025

5.3 Farmer Perception of Digital Agriculture Adoption in Ontario

The chart illustrates the perceived benefits of DATs among farmers in Ontario, based on unpublished survey responses. The most commonly cited advantages are increased crop yields and productivity, along with reduced input costs such as fertilizers and pesticides, both receiving over 150 responses. These findings align with the broader goals of precision agriculture, which emphasizes efficiency and resource optimization. Notably, over 100 respondents also identified

improvements in soil health, land management, and decision-making processes as key benefits, reflecting a growing recognition of DATs' role in supporting sustainable and informed farming practices. While fewer respondents highlighted meeting market demands (e.g., traceability, sustainability) and adapting to climate variability, their inclusion still signals that environmental and market-aligned outcomes are becoming part of the digital transition narrative. Overall, this evidence suggests that Ontario farmers primarily value DATs for their economic and operational benefits, but there remains potential to strengthen awareness of their environmental and resilience-enhancing capabilities, particularly in the face of climate change.

Figure 8

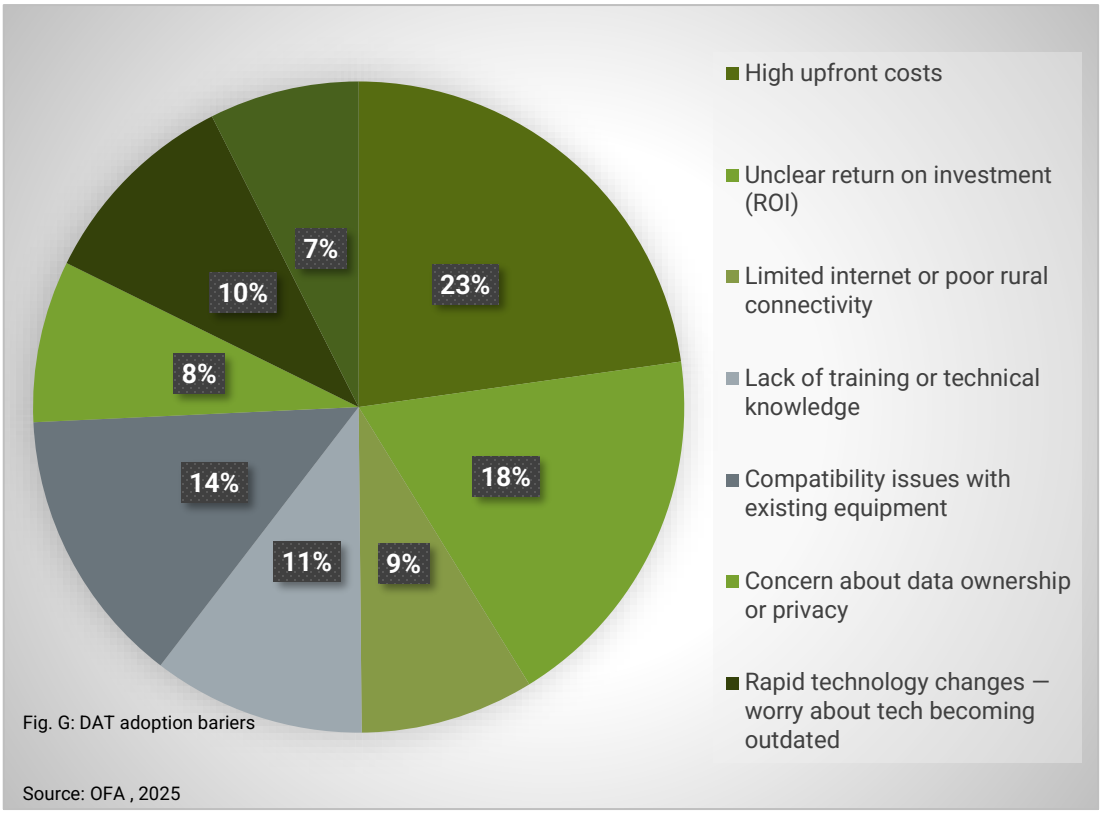


Fig. G: DAT adoption bariers

Source: OFA , 2025

Barriers to DATs adoption in Ontario

The pie chart reveals the primary barriers farmers in Ontario face when adopting Digital Agriculture Technologies (DATs), which in turn affects the province's ability to build climate-resilient agricultural systems. The most cited constraint—high upfront costs (23%)—underscores a critical financial barrier that limits access to technologies capable of reducing emissions and improving adaptation, such as precision irrigation or GPS-guided machinery. Concerns about unclear return on investment (18%) and lack of training or technical knowledge (14%) further hinder adoption, highlighting the need for targeted support programs, including cost-sharing models, training, and extension services. Limited internet or poor rural connectivity (8%) also reflects a significant infrastructural gap that must be addressed to unlock the full potential of DATs in enhancing on-farm climate resilience. As Ontario's agriculture sector increasingly integrates data-driven tools to manage extreme weather, optimize inputs, and monitor environmental impact, overcoming these barriers is essential. Addressing these constraints through coordinated policy, investment, and stakeholder engagement will help ensure that digital agriculture contributes effectively to the province's broader climate action and food system sustainability goals.

Figure 9

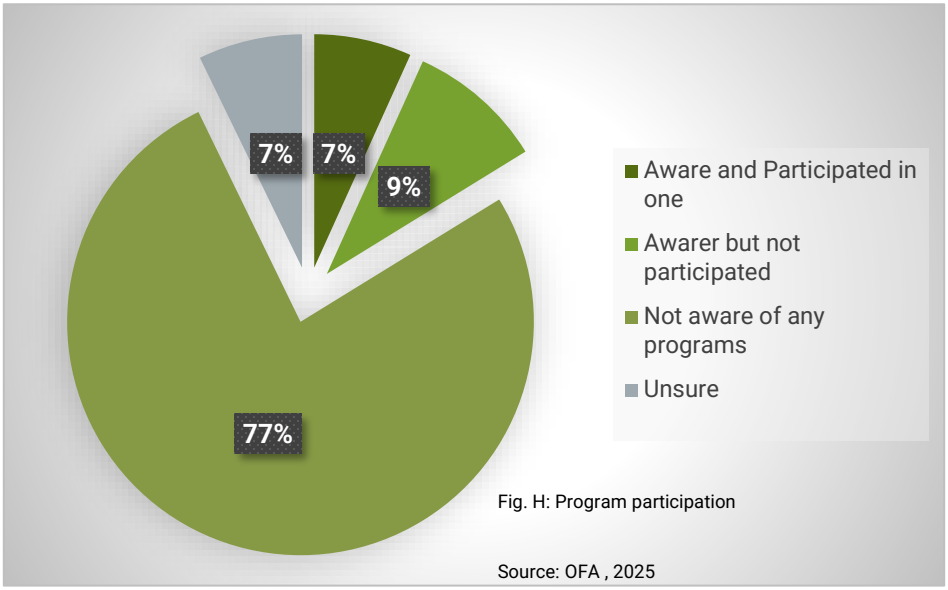


Fig. H: Program participation

Source: OFA , 2025

The pie chart (Fig. 9) reveals a critical communication and outreach gap in Ontario's digital agriculture transformation: 77% of farmers surveyed are not aware of any programs related to Digital Agriculture Technologies (DATs), while only 9% are aware but have not participated, and a mere 7% have both awareness and experience with such programs. This lack of awareness poses a substantial barrier to leveraging DATs for climate resilience, particularly in regions where adoption could play a pivotal role in reducing emissions and improving adaptive capacity. Without targeted policy interventions, such as well-publicized DAT pilot projects, community-driven demonstration farms, or region-specific DAT information campaigns, the transformative potential of digital tools to enhance soil health, reduce input usage, and adapt to climatic shifts will remain untapped. Bridging this awareness gap is essential for creating inclusive, climate-resilient agri-food systems in Ontario and achieving broader environmental policy goals.

5.4 Key findings

With about 98 percent broadband coverage, Ontario has invested over $3.5 million in broadband infrastructure across urban and rural areas. (Government of Canada, 2024). Therefore, Broadband accessibility was used as a proxy for DAT adoption since it is a required service to facilitate the provision of DAT operations and adoption (Hambly, 2016).

- **High-Adoption Zones:** Found predominantly in **southern and central Ontario**, large-scale agribusinesses have access to capital, infrastructure, and digital literacy programs. These regions exhibit:
    - Widespread use of **GPS-guided precision agriculture tools**.
    - Integration of **UAVs for crop monitoring**.
    - **GIS-based farm management systems** supporting decision-making.
- **Low-Adoption Zones:** Concentrated in **northern and eastern Ontario**, where:
    - Small-sized farms **lack financial resources** for digital investments.
    - **Limited rural broadband** supply restricts real-time data usage.
    - **Skepticism and low digital literacy** hinder uptake.
- **Environmental Implications:**
    - Regions with **higher DAT adoption show better resource efficiency** (e.g., precision irrigation and reduced fertilizer overuse).
    - **Low-adoption areas exhibit higher soil degradation risks** due to conventional farming practices.

The findings underscore the need for a structured policy response to enhance the role of digital agriculture in climate resilience. Key takeaways include:

The digital divide must be addressed: Targeted support is needed for small-scale farmers and low-adoption regions to prevent widening gaps in technological access.

- **Stronger institutional coordination is required:** A dedicated Digital Agriculture Policy Framework should align federal and provincial efforts.
- **Capacity-building is critical:** Investments in training programs, extension services, and research-farmer partnerships are essential to maximizing DAT benefits.
- **A data governance framework is needed:** Clear policies on farm-level data privacy, ownership, and security must be developed to build trust in digital agriculture.

Policy awareness and participation

- A significant majority of Ontario farmers (77%) are unaware of any existing programs supporting Digital Agriculture Technologies (DATs) for climate resilience, indicating a major communication and outreach gap.
- Only 9% of farmers reported being aware of such programs but had not participated, suggesting possible barriers beyond awareness, such as trust, access, or perceived relevance.
- Just 7% of respondents had both awareness and active participation in DAT-related programs, highlighting critically low engagement rates with available policy initiatives.
- Another 7% were unsure about the existence of any relevant programs, further emphasizing the need for clearer and more accessible information dissemination by policymakers and program implementers.

6. Policy Implications

6.1 Bridging the Digital Divide in Ontario's Agriculture

The spatial analysis revealed unequal access to DATs, with large agribusinesses in high-adoption regions benefiting significantly, while small and mid-sized farms in rural and northern Ontario face persistent adoption barriers. Addressing this gap is essential for building equitable resilience, ensuring that all producers can harness digital tools to adapt to climate change and contribute to sustainable food systems.

Policy Actions:

- **Expand digital infrastructure investment**: Improve rural broadband connectivity (not only access but speed) to enable real-time data use in precision agriculture.
- **Introduce targeted financial incentives for smaller-scale farms:** Develop subsidies, tax credits, or cost-sharing programs tailored to the unique economic realities of small and mid-sized farms. These measures should focus on offsetting the upfront costs of adopting context-appropriate DATs, ensuring that technology adoption is economically viable where it makes sense.
- **Support cooperative technology models**: Promote shared digital services, such as cooperative drone monitoring programs and regional GIS-based farm management systems, to lower entry costs.

6.2 Strengthening Government Coordination and Policy Alignment

Ontario operates within a federal system where agriculture is a shared jurisdiction between provincial and federal governments, often leading to cost-shared programs and dual oversight. While this governance model reflects Canada's constitutional structure, it can result in fragmented implementation when it comes to Digital Agriculture

Technologies (DATs). The absence of a coordinated digital agriculture strategy, despite overlapping responsibilities, has contributed to regulatory gaps, uneven support programs, and inconsistent funding mechanisms. Unlike more unified policy environments in countries such as the Netherlands or Australia, Ontario's approach lacks the integrative coherence needed to align DAT investments with climate and sustainability outcomes at the provincial level.

Policy Actions:

- **Develop a Digital Agriculture Policy Framework**: Harmonizing federal and provincial efforts through a unified policy framework could provide a clear, strategic roadmap to accelerate the adoption of Digital Agriculture Technologies (DATs) across Ontario, ensuring alignment, efficiency, and long-term impact. There is an opportunity for this to be a priority in the next Federal-Provincial-Territorial agreement in 2028 approaching this year.
- **Establish an Interagency Digital Agriculture Task Force:** Promote coordinated action among policymakers, research institutions, farmer organizations, and a broad spectrum of agri-tech firms—including equipment manufacturers such as John Deere and AGCO, precision technology providers like Trimble and Raven Industries, and agri-digital startups developing software platforms for farm management, remote sensing, and supply chain traceability. This task force would support cross-sector collaboration, align innovation with on-the-ground needs, and inform evidence-based digital agriculture policies for Ontario.
- **Create region-specific policy instruments**: Adapt policies to local agricultural and ecological conditions, ensuring that DAT adoption aligns with sustainability goals.

6.3 Capacity Building and Knowledge Transfer

The study found that limited farmer training programs and under-resourced extension services contribute to low digital literacy and uneven trust in technology-based farming solutions. While weak extension support is a key barrier, adoption is also shaped by individual factors such as farmers' return on investments, risk tolerance, income levels, and operational preferences. Compared to jurisdictions like the U.S. Midwest, where robust extension networks have accelerated the adoption of Digital Agriculture Technologies (DATs), Ontario risks falling behind in digital integration. Strengthening extension services and targeted training is not just about improving adoption rates; it is a strategic investment in Ontario's long-term agricultural competitiveness and its capacity to adapt to climate and market pressures.

Policy Actions:

- **Expand farmer education and training programs**: Develop digital literacy programs tailored for farmers, emphasizing precision agriculture, UAV operation, and GIS applications.
- **Strengthen extension services**: Integrate digital agriculture advisory services into Ontario's existing agricultural extension framework.
- **Enhance research-farmer partnerships**: Increase funding for collaborative projects between universities, research centers, and farming communities to facilitate on-the-ground innovation.

6.4 Establishing a Robust Data Governance Framework

Farmers express concerns over data privacy, ownership, and security, which hinders trust in digital platforms. The absence of clear regulatory guidelines on farm-level data management poses risks, particularly concerning third-party access and corporate control over agricultural data.

Policy Actions:

- **Develop a regulatory framework for agricultural data governance**: Establish a regulatory framework for agricultural data governance to build trust among producers by clearly defining data ownership, usage

rights, sharing protocols, and cybersecurity standards. Clarifying these elements can address farmers' concerns about data misuse and foster greater confidence in adopting digital agriculture platforms.

- **Create an open-access agricultural data platform**: Facilitate transparent data-sharing between government agencies, farmers, and researchers, while ensuring data security.
- **Mandate ethical AI practices in digital agriculture**: Establish guidelines for algorithmic transparency and fairness in precision farming applications.

6.5 Aligning Digital Agriculture with Environmental and Climate Goals

While DATs offer potential sustainability benefits, their integration into climate adaptation and conservation strategies remain limited. Ontario lacks targeted policies that incentivize DAT use for ecosystem services, carbon sequestration, or regenerative agriculture.

Policy Actions:

- **Introduce sustainability-linked incentives for DAT adoption**: Ontario should offer targeted incentives, such as carbon credits, grants, and eco-certifications, for farms that adopt Digital Agriculture Technologies (DATs) aligned with climate-smart practices. Such outcome-based incentives have proven effective in accelerating sustainable technology uptake and rewarding ecosystem services (FAO, 2023; Rose et al., 2021).
- **Mandate environmental assessments for publicly funded DAT investments**: Requiring sustainability impact assessments for government-supported DAT projects would ensure environmental risks and benefits are evaluated upfront. This would address concerns that technology adoption, without clear environmental criteria, may reinforce unsustainable practices (Benton et al., 2021).
- **Integrate DATs into Ontario's broader climate adaptation strategy**: DATs provide real-time spatial and agronomic data that can inform land-use planning, soil conservation, and water management. Integrating these tools into climate adaptation frameworks would improve policy targeting and system-wide resilience (Balasundram et al., 2023; Yildirim et al., 2019).

7. Conclusion

Digital Agriculture Technologies (DATs) have the potential to transform Ontario's food production landscape, enhancing climate resilience, and agricultural sustainability. However, spatial disparities, policy fragmentation, financial barriers, and weak institutional coordination continue to limit the effectiveness and equitable adoption of these technologies.

This policy paper has demonstrated that while high-adoption zones in Ontario benefit from DATs, small-scale farmers and rural regions face significant constraints, including limited digital infrastructure, high costs, and low digital literacy. The study also highlights governance gaps, particularly the absence of a unified digital agriculture strategy, which hinders coordination among policymakers, research institutions, and industry stakeholders.

To ensure that DATs contribute meaningfully to Ontario's sustainability and food security goals, targeted policy interventions are necessary. This includes:

- **Bridging the digital divide** through expanded broadband access and financial incentives for small-scale farmers.
- **Enhancing institutional coordination** with a dedicated **Digital Agriculture Policy Framework** and interagency collaboration.
- **Building capacity** through farmer training, extension services, and research-driven innovation.
- **Establishing a strong data governance framework** to address privacy concerns and regulate agricultural data use.

- **Aligning digital agriculture with environmental policies** by integrating DATs into climate-smart and regenerative agriculture strategies.

By implementing these measures, Ontario can unlock the full potential of digital agriculture, ensuring that technology serves as a tool for both economic and environmental resilience. A coordinated, inclusive, and forward-looking policy approach is critical to ensuring that DATs contribute to a sustainable, efficient, and equitable agricultural sector.

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