# The Future Governance of Artificial Intelligence in Agriculture: Advancing Justice-Based Approaches

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**Abstract**
In recent years, the use of new and emerging technologies of digital agriculture has (re)produced social and environmental concerns across global food production systems—e.g. data grabbing, heightened surveillance, labor displacement, privacy breaches and repair restrictions. Unfettered from regulations mandating equitable governance, AI-infused technologies can facilitate the consolidation and homogenization of production systems to the detriment of many farming groups. It remains unclear the extent to how justice can be operationalized in governance challenges facing agriculture today. Critically engaging with the framework of Responsible Innovation, this article evaluates whether the integration of justice principles can improve governance outcomes in the spheres of data-based technologies and AI in agriculture. This study foregrounds two case studies—the "right to repair" movement and data-based environmental governance—that reflect different contexts where AI might disrupt current arrangements. After interrogating these cases, the results facilitate the identification of specific risks from AI deployment to the power dynamics of governance challenges. The results consider how inclusion, epistemic justice, and rigid governance approaches can be integrated into justice-informed governance analysis. From roots to circuits of foodspaces turned cyberspaces, justice might still have time to find fertile ground in alternative governance approaches to AI-infused agriculture.

*Keywords:* Governance, Justice, Agricultural Technologies, Artificial Intelligence, Responsible Innovation

## Introduction

Development of Artificial Intelligence (AI), the Internet of Things (IoTs) and robotics in agriculture provides an opportunity to reduce uncertainty in decision-making by generating temporal and site-specific on-farm agronomic recommendations and improving efficiencies across the food system supply chain. AI technologies in agriculture use a wide range of computational techniques aimed at providing new statistical insights that can facilitate more precise management techniques by farmers and environmental agencies. Technologies are promoted as a 'win-win' solution for driving both economic and environmental sustainability in agriculture. However, despite the potential of new technologies to transform agriculture and close gaps in access, quality, efficiency, and food security outcomes, the actual benefits have been unevenly distributed among a range of actors across the value chain. Recent research suggests that AI models that drive new agricultural technologies are opaque, and business-as-usual development of data-based technologies can create harmful biases for people and the environment (Bronson, 2022; Carolan, 2022; Duncan et al., 2022; Stock & Gardezi, 2021).

In recent years, new sensor-based technologies and algorithms being trained on large data sets are being deployed with the intention of improving environmental monitoring and predictions and implementing agri-environmental policies. While there is hope that environmental policy and governance might be subsequently improved by new technologies (Bakker & Ritts, 2018), researchers have raised concerns about some of the risks that might arise by these tools. Scholars have raised concerns about the lack of accountability and transparency derived from the implementation of algorithmic decision-making tools (Ghosh, 2023; Schirpke et al., 2023). The use of data-driven technologies in agriculture has the potential to obscure normative discussions about environmental regulation, providing an aura of neutrality while supporting existing unsustainable practices (Ghosh, 2019). The technocratic logics of eco-algorithmic governance can limit participation by publics in environmental policies and governance (Tironi & Rivera Lisboa, 2023).There are normative and political issues that governance has to address when engaging with new digital technologies (Kloppenburg et al., 2022).

In reaction to the exclusionary impacts of new technologies in agriculture, and in response to a growing need for more holistic approaches to counter big data and AI risks, environmental and technology policy is demanding more socially just outcomes from governance. This paper attends to these demands in the shaping of AI and data-based technologies in agriculture by calling on Responsible Innovation (RI) frameworks to address environmental and technological characteristics as new challenges to agriculture and food systems. In this paper, we build on the pillars of RI, specifically related to reflexivity and inclusion to identify potential risks derived from the intersection between agricultural and AI technologies. Reflexivity helps us to identify the limits and possibilities of technology deployment, while inclusion allows us to create informed scenarios of potential risks to humans and nature. Essentially, this means identifying how technologies and natural environments are currently governed in agrarian spaces, by whom, and to what ends (Stock & Gardezi, 2021). This article aims to answer the following question: What commonalities emerge in how power distribution, knowledge access, and grassroots movements shape governance challenges across agricultural technology and agri-environmental policy domains?

The paper is organized as follows. First, we summarize discussions on two different domains of agricultural governance, agri-tech and agri-environmental governance approaches, that inform the selection of our case studies. Then, we advance critical approaches to Responsible Innovation to develop an analytical framework that is responsive to potential power imbalances derived from AI deployment. Thirdly, we present the two case studies that are representative of each governance approach in agricultural landscapes, the right-to-repair movement and the case of data-based environmental governance. Finally, we provide an analysis of the cases, anticipating the potential risks that AI technologies could generate in the structures of agricultural governance issues that are still unfolding. We contribute to academic discussions about the potential risks of AI technologies and to scholarly debates looking to strengthen governance approaches to AI and the RI framework. The results of the paper provide insights that are relevant to policymakers and stakeholders who are interested in reflecting upon the need for information and knowledge capacity building that strengthen governance strategies in the agricultural sector.

## What AI might disrupt: Agri-tech and Agri-environmental governance

Over the last several decades, researchers have studied how to achieve effective governance arrangements to manage dilemmas in the use or extraction of natural resources (Davidson & Frickel, 2004) and, more generally, environmental public goods (Lemos & Agrawal, 2006). Governance "addresses the multiple political processes and relationships through which state and non-state actors do, and might, engage" (Leach et al., 2007). In the case of farming and agriculture, research on governance has focused either on the environmental consequences of agricultural production or on the ways new technologies might impact farming and food systems. Agri-environmental and agri-tech governance approaches are helpful to contextualize the details of different types of technological development and adoption, and their consequences for different actors.

Particularly in the case of agri-environmental governance, researchers have described some of the issues that farming operations and food systems need to address to comply with goals of sustainable production (Forney, 2016; Forney et al., 2018; Rodríguez-Ortega et al., 2018). Agri-environmental governance seeks to balance multiple environmental concerns while attempting to sustain or transform current agricultural landscapes. Agri-environmental governance strives to respond to problems derived from contemporary agricultural practices like the exploitative use of common resources (e.g. water), pollution derived from the expansion of farming operations and deforestation, biodiversity loss, greenhouse gas emissions, and adaptation to climate change and extreme weather events (Alblas, 2023; Bazzan et al., 2023; Forney et al., 2018; Forney & Epiney, 2022).

Technology governance in agriculture has evolved along a trajectory distinct from that of agri-environmental governance. Agricultural technology or "agri-tech" governance has mostly been concerned with technological adoption and diffusion, building upon rationalistic understanding of technology use and linear conceptions of innovation processes (Higgins & Kitto, 2004). Recently, data-based technologies have come to the forefront of agri-tech governance analysis. Adesola Anidu and Rozita Dara (2021) have approached agri-tech governance from a computer science perspective by analyzing the different stages of data production. However, their review pays little attention to broader conceptions of governance, since it takes a primarily technical standpoint linked with ideas such as interoperability, standardization, and use of data. Van der burg et. al. (2019) have identified three general aspects of ethical concern in relation to agricultural technologies: data ownership and access, distribution of power, and impact on human life and society. While their review of the literature is useful in delineating the importance of ethics for governance, they do not provide a detailed analysis of particular technologies within food and agriculture systems. Lioutas and colleagues (2019) explored numerous questions derived from the intersection of new technologies (big data and AI) and farming practices, detailing many governance problems that remain unaddressed to this date.

To date, the work of Michael Carolan and Cristian Timmermann stand out as research approaches that consider the role of justice approaches in relation to technological innovation in agriculture. Carolan's (Carolan, 2024) work provides a theoretical and methodological framework that encourages moving from theoretical understandings of justice to practical applications. Carolan's research examines the effects of new technologies on farmers' social identities, particularly focusing on individuals who identify as having a disability. This approach offers a rare and pioneering example of applying justice-based perspectives to marginalized agricultural communities and identities. Timmerman takes a broader look at agri-food systems, emphasizing the role that new technologies can play in fostering food access and security. Timmerman also considers the potential problems new technologies might create, addressing the connections between land concentration and technological advancements (Timmermann, 2020).

Critical agricultural scholarship on governance could greatly benefit from more approaches driven by justice-based approaches (Clapp et al., 2018), which consider the structural implications of technologies in specific contexts. In this quest for answers to agricultural governance challenges is helpful to illuminate the possible orientations that governance can take, and how new justice-based perspectives can be developed.

**Responsible innovation as a foundation for justice-oriented governance analysis**

Governance can be an inclusive undertaking, or a process directed by only a small group of interested parties. In this regard, the literature and practice of governance has traditionally defined top-down and bottom-up approaches that either promote the involvement of citizens, users, and advocacy groups or, on the other hand, decide ideal governance arrangements via the role of experts (Stringer et al., 2020). A significant risk in inclusive approaches to innovation governance, however, is the instrumentalization of inclusion—where stakeholder engagement is treated as a procedural step rather than a substantive transformation in governance (Mamidipudi & Frahm, 2020). If participatory mechanisms are merely symbolic, they can reinforce existing hierarchies rather than challenge them. Building upon discussions of inclusion in the area of innovation governance, the framework of Responsible Innovation (RI) aims to deliver a governance approach that transforms traditional approaches to innovation governance by making science and technology more responsive and reflexive to ethical, social, and environmental considerations (Stilgoe et al., 2013; Von Schomberg, 2013). Unlike conventional models of technological development that primarily emphasize economic viability of innovation, RI integrates equity and justice into innovation design, evaluation, and governance (Von Schomberg, 2013). This framework has been applied across various technological domains, including nanotechnology (Fisher & Rip, 2013), geoengineering (Stilgoe, 2015), and synthetic biology (Tucker & Zilinskas, 2006), demonstrating its adaptability in guiding research in different economic contexts.

In agriculture, RI has been used to examine collective responsibility in the digitalization of food systems and supply chains (Bronson, 2019; Gardezi et al., 2022; Klerkx & Rose, 2020; Rose & Chilvers, 2018). While previous research has used RI to analyze the effects of new technologies in agriculture, we contend that there are still opportunities to further expand RI so it can foster anticipatory practices that are attentive to normative issues of governance. Scholars argue that inclusive dialogue with diverse agricultural stakeholders can help identify points of contestation and consensus, ensuring that innovation trajectories are shaped through participatory governance (Eastwood et al., 2017). This participatory approach allows stakeholders to anticipate unintended consequences of emerging technologies—such as inequitable access to digital agriculture tools—and take proactive steps to shape more just and equitable innovative (van der Burg et al., 2019). Previous research has provided relevant analyses of agricultural governance in relation to new technologies, building on the RI framework and identifying new research avenues, but the potential of its core features to address emerging technological challenges requires a deeper examination of the theoretical pillars of RI.

Despite RI's promise to expand inclusive innovation, scholars critique its implementation as being constrained by traditional innovation models that reinforce power asymmetries and limits its ability to address deeply rooted structural and societal injustices (Braun, 2024; Papaioannou, 2024; Stirling, 2024). Braun (2024) argues that RI often operates within a linear problem-solving framework, where technological solutions are designed to address perceived societal deficits. This modernist perspective on RI often fails to interrogate the deeper ontological and political structures shaping technological governance. Instead of merely assessing the impacts of innovation, Braun suggests that RI should embrace radical reflexivity—a method that questions the foundational assumptions and power dynamics behind scientific and technological development.

Other scholars suggest that RI should more actively drive epistemic justice—ensuring that multiple ways of knowing are valued in innovation processes (Macnaghten & Guivant, 2020; Mamidipudi & Frahm, 2020; Ottinger, 2023). An engagement with epistemic justice provides RI an instrument to deal with knowledge politics, narratives entangled in power structures, that can remain obscured by neutral references to inclusion and responsiveness (Di Giulio et al., 2016). Epistemic inclusion challenges the dominance of scientific expertise in defining risks and solutions, advocating for co-production of knowledge were stakeholders' lived experiences shape decision-making. This shift is particularly relevant in agriculture, where, for example, farmers' local knowledge is often marginalized in favor of algorithmic decision-making systems (Carolan, 2022; Stock & Gardezi, 2021). Epistemic resources serve as mental shortcuts that help people think critically and understand abstract concepts such as the measurement of various pollutants in environmental monitoring. When researchers assist communities in constructing these resources, it can lead to the development of vocabularies that counteract epistemic injustices (Fricker, 2007).

Governance arrangements, particularly for data-driven and emerging technologies, must also navigate high levels of complexity. Acknowledging complexity and uncertainty in governance approaches has also served to promote inclusion, suggesting that the involvement of more diverse stakeholders provides ways to reduce uncertainty by including multiple voices (Felt, 2015; Jasanoff, 2003; Scoones & Stirling, 2020). Traditional RI approaches look to address and manage complexity and uncertainty under the analytical categories of anticipation and reflexiveness. In contrast, a heuristic model developed by Kuhlmann et al. (2019) looks to integrate diverse approaches to deal with uncertainty by engaging with the idea of tentative governance, broadening the scope of governance approaches that could be useful to deal with the potentials and risks of new technologies. Echoing the necessity of responsiveness and management of complexity in governance that is present in RI approaches, especially as it relates to emerging technologies, Kuhlmann et al. (2019) argue for a tentative approach to the governance of emerging technologies that provides time and space for technologies to interact with users and real-world settings before deciding on a specific approach to regulation. A tentative approach to the governance of emerging technologies recognizes the value of flexibility and adaptation, as opposed to more definitive approaches that are unable to revise and modify their enactment. While claiming to be impartial in normative terms, the governance of new technologies often prioritizes tentativeness and experimentation over more definite or rigid approaches. However, frameworks that rely on the tentativeness/definiteness axis need to be reflexive in how they engage concerns of equity when applied in practice (Lyall & Tait, 2019). This is especially relevant when new and emerging technologies interact with historically determined governance spaces like agricultural systems, where existing power structures are already in flux.

While RI holds significant potential in addressing social justice concerns, its effectiveness depends on its ability to move beyond procedural inclusion toward substantive power redistribution (Papaioannou, 2024). The principle of reflexivity within RI can be strengthened by interrogating hidden power structures, embracing epistemic justice, acknowledging historical governance approaches, and recognizing the agency of diverse stakeholders in shaping technological adoption or rejection. This generative critique to the RI framework situates our approach in a critical perspective related to the normative foundations of the RI literature (Fisher et al., 2024)m or what might be considered more simply as a critical RI lens.

Drawing from the theoretical components previously discussed, our analytical approach is summarized in figure 1. Leveraging critical assessments of frameworks anchored in RI, this perspective allows us to anticipate the effects of AI in agricultural technologies in different potential use cases. By considering how current governance arrangements are structured, we can better project how AI technologies might integrate, disrupt, or enhance the social and historical conditions that have shaped them.

**[Production: insert Figure 1 here]**

## Interrogating technological governance in PA from a critical RI lens via two case studies

In this section, we present two case studies that reflect different ways through which new and emerging technologies in agriculture are governed. These cases include: (a) The right-to-repair movement, and (b) data-based agri-environmental governance. Each case is examined through a critical RI lens to describe features relevant to a justice-enhanced and critical RI reflexive approach. Our methodological approach in this research involves a comparative case study focused on two recent governance approaches, selected to represent contrasting dimensions of agricultural governance. The right-to-repair case study directly considers the use of machinery and tools in agriculture, where AI is already being deployed in newest models. The data-based environmental governance case is selected to reflect how information and technology mediates environmental management. The two cases also reflect distinct controversies in agrarian spaces where AI deployment might destabilize existing governance arrangements.

Case studies give researchers a methodological strategy that helps to create robust studies when the variables of interest are more than what could be captured through quantitative analysis alone. This strategy has been successfully used in academic fields related to technology and innovation (Ebneyamini & Sadeghi Moghadam, 2018). A case consists of a specific story or narrative that can be circumscribed to a specific phenomenon (Gerring, 2004). A comparative approach to this method aims to provide information about a variety of cases that allow researchers to develop new insights and theories from their similarities and differences. The cases are selected to showcase variations in type, innovation processes, and societal impact, following a style of intentional sampling that is usual for case study methods (Moynihan, 2009).

Choosing case study methodology is ideal for our research aims as it leverages publicly available data on governance, enabling us to focus on regulatory outcomes rather than processes. Each case represents different stages of development and presents various challenges, both tangible and intangible. The right-to-repair movement case was selected due to its prominence in the field of robotization and its significant structural impact on contemporary agriculture. The data-based governance case was included due to the relevance of data to guide, support, and legitimize governance approaches. These cases also vary in their level of impact of confronting and addressing uneven power relations in agricultural governance. These cases allow us to examine a broad spectrum of the governance of innovation within the agricultural sector. Overall, these cases describe the different causes of power imbalances and how diverse types of governance approaches have been used to promote or negate inclusion, fostering normative claims, and protecting rights and fulfilling expectations.

### *Right-to-repair, DRMs, and machines for precision agriculture*

In 2015, the Library of Congress ruled in favor of allowing exemptions on the possibility of circumventing technological protection measures in certain technologies with the intention of repairing them. The ruling brought to the general public's attention the restrictions placed by manufacturers such as General Motors and John Deere on the possibility of accessing the hardware and software of their products. Companies have used digital rights management tools (commonly known as DRMs) to restrict access to proprietary information and limit the usage of digital copies of single-user license commodities; software technology that supports agricultural production is no exception.

The controversy about the right of owners to repair their vehicles without losing warranty on the products they purchased is well documented in public discourse and academic literature (Perzanowski, Aaron, 2022). The now famous case of farmers not having access to repair the hardware they own sparked a grassroots movement that is fighting for the ‘right to repair’ as a legal exception to copyright law. The main problem arises from changes to how technologies are created and deployed, but it extends into concerns about market competition and ownership regulations. As agricultural equipment has become more complex, software solutions have been developed to integrate sensors and data into the daily operations of tools such as tractors. Companies argue that limits to repair are centered around protecting their intellectual property and making sure that the machines operate as intended. The proper operation of emission-related components has also been used by manufacturers to invoke limits to who can modify the tools and equipment owned by farmers (National Farmers Union, 2023). Regulatory agencies and farmers argue that restrictions on repair practices provide manufacturers with the power to control the price of repair services, limiting the possibilities of independent repair shops and individuals to make the necessary improvements.

After other agreements between companies and farmers throughout the years have failed to deliver a satisfactory solution to users, the latest advancement on this subject has been a Memorandum of Understanding that promises steps to ensure the right to repair farmers’ equipment as long as they stop promoting legislation on this matter (PIRG, 2023). This latest approach by agri-tech companies is an attempt to develop governance approaches that are voluntary in nature, and thus harder to enforce, but might provide more immediate relief to the affected farmers than more institutional approaches. The case of the right to repair agricultural equipment has become a prime example of the ways grassroots organizations have responded to unilateral decisions about the governance of technology from powerful agri-tech corporations. The impulse of the argument has created spillovers that go beyond the U.S., influencing institutional responses to protect farmers’ right to repair from countries like Australia (Australian Government Productivity Commission, 2021).

Broadly speaking, opposition to legislation that affirms right-to-repair hardware is enacted through legal challenges and the political lobby of manufacturers, limiting the advancement of state-level legislation (Boniface et al., 2024). In the U.S., the issue has played out mostly at a state-level of institutional governance. In 2023, at least 33 states debated legislation that related to right-to-repair demands, with Colorado being the only of those proposals enacted into a legislation that directly references agricultural equipment (National Agricultural Law Center, n.d.). The Colorado law has been in effect starting on January 2024, and its effect on farmers’ demands, the repair market, and more broadly on other legislations is yet to be seen (Gass, 2023). Notably, days before the end of the presidential term of Joe Biden, the head of the Federal Trade Commission filed a lawsuit against Deere & Company arguing that their behavior has restricted repair rights of farmers. The rationale for the lawsuit also cites the possibility that AI could be used to engage in anticompetitive behavior that restricts the right to repair (Khan, 2025).

Optimistic analyses of the impact of AI in agriculture see a potential for efficiency and overall improvement in data management, processing, and prediction (Javaid et al., 2023; Wakchaure et al., 2023) . Nevertheless, there are concerns that new technologies based on AI might help to lock in industrial production and leave behind alternative ways of farming (Bronson et al., 2021). There are also ethical apprehensions regarding the effects AI technologies might have on employment, sustainability, trust, and potential risks and harms, among others, if they are implemented in the agricultural sector (Ryan, 2022).

New technologies have the quality of illuminating tacit agreements between users and suppliers that were previously unquestioned. Modifying and tinkering with technology has been something that most producers have always done. However, new technologies produce a torrent of data and a windfall of profit, motivating agri-tech firms to protect and enclose the knowledge produced. Managing interests regarding intellectual property, responsibility for the proper working of the machinery, and losing guarantees if something goes wrong are all issues that governance arrangements must deal with. Intellectual property has always been a contentious issue when it comes to governance, looking for the balance between fostering innovation and the right of users to act as creators or tinkerers. Table 1 shows a summary of the case study in relation to the main components of our theoretical perspective.

| **Principles of Responsible Innovation** | **Right-to-Repair Case (Agritech Governance)** |
|---|---|
| ***Inclusion*** | ***Who gets a voice in governance?*** |
| Who is included? | Farmers, grassroots activists, independent repair shops, and trade associations that advocate for repair rights. |
| Who is excluded? | Farmer autonomy is restricted by agri-tech corporations that control access to repair technologies. |
| Forms of engagement? | Grassroots activism, legal challenges, and lobbying efforts push for right-to-repair legislation. |
| Limits of inclusion | While farmers push for repair rights, voluntary agreements (like the Memorandum of Understanding) fail to redistribute power. |
| ***Reflexivity*** | ***Questioning underlying assumptions in governance*** |
| What dominant assumptions shape governance? | Agri-tech corporations claim that restricting repairs protects intellectual property and ensures proper machine operation. |
| What perspectives challenge these assumptions? | Farmers argue that repair restrictions increase costs, reduce autonomy, and create market monopolies. |
| How does governance respond? | The shift toward voluntary agreements (e.g., Memorandum of Understanding) acknowledges farmer demands but avoids legally binding commitments. |
| What are limits to reflexivity? | Agritech firms fail to recognize that under some situations farmers' ability to repair and innovate can override intellectual property protections. |

Table 1. Summary of RI principle in the right-to-repair case. Source: Own elaboration

***Data-based Agri-environmental governance in Vermont***

Historically, agri-environmental systems and associated non-point source pollution and private property landownership regimes have been termed 'wicked problems' due to the public-private tradeoffs of goods and services leading to externalities (Farley & Voinov, 2016; Ostrom, 2010). To solve this wicked problem, identifying and monitoring the sources that are responsible for pollution becomes one possible governance approach (Koliba et al., 2014). In support of these efforts, computational models that simulate complex human-environmental interactions across spatial and temporal scales are being tested and deployed (Ding et al., 2024; Fang et al., 2024; Wang et al., 2022). New AI-based techniques and models are expected to advance the identification and monitoring of soil-water quality dynamics, aiding in the governing process by leveraging higher-resolution data (Cheng et al., 2022; Kemper et al., 2025).

A transboundary watershed shared between the Province of Quebec, Canada and the US states of New York and Vermont, the Lake Champlain Basin (LCB) has been facing eutrophication resulting in public health challenges (i.e. drinking water and Harmful Algal Blooms (HABs)) due to phosphorus pollution stemming from a variety of sources in agriculturally dominated-watersheds (Ghebremichael et al., 2010). Under the Clean Water Act, the United States Environmental Protection Agency (EPA) tasked the State of Vermont with reducing phosphorus flowing into Lake Champlain. The EPA established the Total Maximum Daily Load (TMDL) in 2002 and revised it in 2016 using a biogeochemical model, Soil Water Assessment Tool (SWAT) (Environmental Protection Agency, 2016).

The contemporary structure behind the governance attempts to reduce phosphorus levels in the Lake Champlain basin can be traced to the Clean Water Act and the development of the TMDL targets to monitor and control phosphorus pollution in the freshwater system. In 2002, the state of Vermont approved a specific TMDL that was challenged by environmental organizations in court due to its lack of scientific background and relevant targets to reduce pollution in practice (Osherenko, 2014). Establishing monitoring schemes based on TMDL allows regulatory agencies like USDA to continue using incentive programs as their main style of environmental governance intervention. This style is defined in part by the cultural limits to regulatory practices of agriculture and farms (Osherenko, 2014).

An updated version of the TMDL was developed in 2011 and 2016 by the Vermont Agency for Natural Resources (Bitterman et al., 2023), which was mandated to include the participation of a varied range of stakeholders, including public consultations and the involvement of NGOs and researchers into the governance network (Koliba et al., 2014).

In parallel to institutional approaches to governance, there is also direct community involvement in capturing data to monitor pollution through the support of a non-profit environmental organization and citizen science approaches. This citizen-led approach is concerned with monitoring the effects of phosphorus pollution, the algae blooms, instead of the TMDL. They monitor the health of the lake through citizen networks to detect cyanobacteria, the bacteria behind the development of blooms that are present in Lake Champlain (Vaughan et al., 2021).

The legal challenges to regulation are a constant feature of the governance structure. In the context of discussing the development of new agricultural rules in 2016, farmers and civil society organizations expressed concerns about the approach taken to govern pollution in the LCB. Farmers argued that small operations cannot cover the costs of environmentally friendly practices, while environmental organizations argue that regulations are not doing enough to protect people and nature (Rathke, 2016). More recently, three environmental organizations (the Conservation Law Foundation, Vermont Natural Resources Council, and Lake Champlain Committee) petitioned the Environmental Protection Agency (EPA) to act upon failures in oversight by the State of Vermont in controlling and monitoring pollution derived from concentrated animal feeding operations. The organizations argued that these oversights are creating a situation where the state is not complying with the Clean Water Act. Following the petition, the EPA conducted inspections and confirmed the claims from the environmental organizations, notifying the state about their deficiencies in enacting agri-environmental policies (Rathke, 2024).

Performance-based payments, aligned with the New Public Management paradigm, are being tested in a variety of geographies targeting various ecosystem services (Frederickson, 2015), including the Lake Champlain Basin. With grant funds from the USDA, a performance-based payment for ecosystem service program titled the pay-for-phosphorus (PFP) program, is being piloted in Vermont with the goals of motivating innovative and site-specific phosphorus reductions and collecting data for TMDL reporting. The model used to determine performance outcomes in this program is the Agricultural Policy/Environmental eXtender (APEX) (Steglich et al., 2023). The APEX model, to be site-specific, requires field-level input data including management records (cropping, fertilization, tillage), soil tests, manure tests, and field boundaries. This geographic specificity that increases spatial targeting and cost-effectiveness, is only possible due to existing policy assemblages that mandate extensive record-keeping and soil tests at the field level for nutrient management plans as part of the Required Agricultural Practices under Act 64 of 2015.

While currently at an early stage in technological development, knowledge-based machine learning (Liu et al., 2024) is expected to outperform process-based models that do not capture complex biogeochemical processes. Elsewhere, the availability of data is already supporting the deployment of AI-based monitoring of ecological outcomes (Tironi & Rivera Lisboa, 2023). Infusing model-based payments with AI-based calculations and outputs introduces different types of uncertainty and risk due to the opaqueness of inputs, predetermined parameters within the model and assumptions on their values and interactions. In addition to the underlying uncertainties of data-based approaches to the governance of phosphorus pollution, the governance approach could prove to be harder to monitor by the environmental groups that have shaped the way that water pollution has been addressed by the state. Access to the data and models is increasingly relevant to support the type of public involvement in agri-environmental governance that this case study has described. The main components of this case study are summarized in table 2.

| Principle of Responsible Innovation | Agri-environmental governance in Lake Champlain |
|---|---|
| ***Inclusion*** | ***Who gets a voice in governance?*** |
| Who is included? | Farmers, environmental groups, state agencies, and citizen scientists participate in decision-making processes. |
| Who is excluded? | Regulatory agencies and scientific experts dominate phosphorus governance, limiting farmer influence. |
| Forms of engagement? | Citizen science initiatives provide community-driven monitoring, but institutional decision-making remains expert-led. |
| Limits of inclusion | Public consultations exist, but scientific modeling (e.g., TMDL, APEX) dictates governance, sidelining local and traditional knowledge. |
| **Reflexivity** | **Questioning underlying assumptions in governance** |
| What dominant assumptions shape governance? | Regulatory agencies assume that scientific modeling (TMDL, APEX) provides the most objective basis for decision-making. |

| | |
|---|---|
| What perspectives challenge these assumptions? | Farmers and environmental groups challenge the reliability of models, arguing they fail to capture real-world pollution impacts. |
| How does governance respond? | The EPA revised TMDL models after legal challenges from environmental groups, but the reliance on technical expertise remains dominant. |
| What are limits to reflexivity? | Policymakers fall short of fully integrating farmer knowledge and citizen science into phosphorus governance. |

Table 2. Summary of RI principle in the data-driven environmental governance case. Source: Own elaboration

**From current case studies to the potential effects of AI**

The case studies previously discussed show the many complexities involved in the process of governing new technologies in agriculture. Software, hardware, data, and ethics are all involved in multiple configurations with farmers, technology developers, policy-oriented actors that help us understand the difficulties of defining general best practices of prescriptions that improve the power imbalances derived from new and emergent technologies. Nevertheless, a critical appraisal of RI dimensions applied to the governance of agricultural technologies could provide policymakers and other grassroot actors with analytical tools that avail alternative governance configurations to engender more equitable agricultural futures.

The case studies show how power and resistance are wielded in agricultural governance though interconnected dimensions. The right-to-repair case shows how corporations deploy legal and lobbying strategies to keep control of the repair market. The data-driven environmental case reveals how institutions work to deploy governance strategies that are at odds with scientific and public consensus. Power dynamics are in conversation with the ways inclusion is conceived and performed. In the case of data-driven environmental governance, inclusion is managed through public consultations, facilitating oversight by environmental groups on agreements and ways to enact them. In the right-to-repair case, inclusion is managed through the Memorandum of Understanding, an overt way of avoiding legal consolidation of repair exceptions.

The cases reveal that rigidity might play a critical role in supporting the rights of consumers and citizens, providing new arguments to downplay the importance of tentativeness and adaptation. While these last features of governance approaches are often regarded as valuable qualities in technology governance, their enactment has a chance of eroding structures that support the distribution of power in equitable terms. In relation to concerns about epistemic injustices, both cases show that grassroot knowledge is usually less valued by dominant governance strategies. In the case of the right-to-repair movement, the epistemic claims on how to interact with technologies are subordinated to repair systems controlled by large corporations. In the case of data-driven environmental governance, citizen science works as parallel system of oversight that is not integrated by institutional definition of how pollution should be measured.

These examples show how a critical approach to the governance of data-based technologies in agriculture could give practical avenues for the stakeholders involved in the promotion of more equitable farming systems. Table 3 provides a summary of our analysis and shows the integrative logic of governance and justice-informed approaches.

| **Governance challenges** | **Right-to-Repair (Agritech Governance)** | **Payment for ecosystem services in Vermont (Agri-environmental governance)** |
|---|---|---|
| Regulatory resistance and corporate power | Agritech corporations use lobbying and legal challenges to prevent right-to-repair laws. | Farmers and environmental groups clash over phosphorus regulations, with industry pushing back against stricter oversight. |
| Procedural versus real and meaningful inclusion | Voluntary agreements between agritech firms and farmers offer procedural inclusion but fail to redistribute power. | Public consultations exist, but regulatory decisions remain expert-driven, limiting farmer and community influence. |
| Epistemic justice | Farmers' knowledge of machinery maintenance is devalued in favor of corporate-controlled repair systems. | Citizen science initiatives challenge expert-led governance, advocating for the legitimacy of local environmental monitoring. |
| Bottom-up or top-down approaches to governance | Grassroots movements advocate for user rights against corporate control. | Citizen monitoring groups counterbalance government-led environmental regulations. |
| Governance responses and existing structures | Rigidity of legal arrangements facilitated right-to-repair restrictions and exemptions. A tentative approach to technology governance has supported power imbalances between producers and users. | Rigidity of existing laws facilitates citizen oversight. Tentative approaches to technology governance could erode the robustness of legal environmental oversights. |
| Effects of AI deployment | AI could provide new arguments, like national security or economic benefits of new technologies, to support digital locks and restrict farmers' ability to modify equipment. | Access to phosphorus pollution models and data transparency remain concerns in performance-based governance. |

Table 3. Summary of case studies. Source: Own elaboration

When it comes to anticipating the effects of AI technologies in agriculture, the case studies provide us with an opportunity to reflect on their implications in different dimensions of the analysis. In the case of environmental governance, the deployment of AI tools to curb pollution could create black boxes that limit the capacity of grassroots of organizations to engage in oversight activities. Additionally, relying on AI-based support tools could aggravate epistemic injustices by supporting types of knowledges that are algorithmically determined. In the case of agricultural machinery, the integration of AI technologies could provide manufacturers with new arguments to limit repair activities that rely on framings of national security, competitiveness, and innovation. The evolution of the global political economy of AI, the large investments by Silicon Valley, the race to be the dominant global power in the technological landscape, could supersede the claims made by consumers and farmers to directly interact with their tractors and support systems. In both cases, the significant economic backing of AI is likely to support tentative strategies that facilitate the ethos of “move fast and break things”, risking the historical gains of consumers and users that are crystallized in rigid forms of governance.

**Conclusion**

In this study, we have detailed different dimensions of governance that the RI literature has overlooked, but that are critical for a comprehensive anticipatory analysis of the potential impacts of AI technologies in agriculture. The two case studies reveal that already existing power imbalances can be critical to anticipate the risks of AI technologies in agriculture. We showed that a critical engagement with the framework of RI can reveal underlying power dynamics in governance arrangements, such as epistemic exclusion, instrumentalization of inclusion, and a predilection for technological development over citizens’ rights. We need varied approaches to governance depending on the potential causes of inequities resulting from power asymmetries in industry. Even if uneven power relations emerge from the structural conditions of the market, where suppliers are responsible for innovation in the industrial sector, governance arrangements should be focused on promoting new technologies while caring for the rights of users and nature.

In this sense, governance approaches directed at AI technologies should be mindful of already existing governance structures to deal with the complexities of specific sites and modes of production, where technology might behave in new and unexpected ways. These findings support the claim that in looking for novel approaches to governance, among them the calls for adaptation, responsiveness, and tentativeness, traditional RI approaches foster uncritical technological adoption (Stirling, 2016)

One of the most relevant insights from the selected case studies is the role played by consumers, users, and grassroots organizations. Since most of the power asymmetries in the industry originate in knowledge and information, successful governance arrangements will require the attention of users, farmers, and diverse stakeholders of food systems and technology value chains to decide on the optimum balance between benefits and risks.

Future avenues of research in this matter would benefit from a deeper understating of specific benefits for producers utilizing AI technologies and their role in new and emerging practices. From roots to circuits of foodspaces turned cyberspaces, justice might find fertile ground in governance approaches to AI-infused technologies that are mindful to the historic nature of the field’s power dynamics.

Finally, the case studies allow us to reflect on the similarities between the two different approaches to governance. Although they have traditionally addressed separate issues, the intersection of emerging technologies and environmental concerns has become increasingly difficult to overlook. New technologies are having a profound impact on environmental governance. Expectations and framings surrounding a more connected and ‘datafied’ world supports a technocratic approach to governance that limits farmers’ autonomy (Forney & Epiney, 2022). Data-driven agri-environmental approaches can hide conflicting valuations of environmental problems and solutions, obscuring political disagreements and weakening accountability (Ghosh, 2023). While research on these topics is valuable, they only consider the effects of new technologies on agri-environmental governance, leaving the possibility of integration unexplored. Existing research mainly overlooks the potential for more robust governance approaches that can be strengthened by bridging agri-tech and agri-environmental perspectives. Agri-technological and agri-environmental governance analyses and practices have been deployed separately, but their convergence is increasingly important to manage the impacts of new technologies in agriculture and food systems.

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**Captions:**

Figure 1. Summary of analytical framework. Source: Own Elaboration

**Alt text**

Circular diagram illustrating two key principles of Responsible Innovation for agricultural governance. Left circle represents Inclusion, showing four questions about who is included and excluded. Right circle represents Reflexivity, showing four questions about questioning assumptions in governance.