Optimizing Stewardship of the Land?

Exploring the Environmental Sustainability Dimensions of Digital Agriculture in Canada

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Abstract

Digital agriculture (DA) is understood as an approach to agriculture that is high-tech and data intensive; it includes technologies such as robotic machinery, big data applications, drones and remote sensing. Proponents of these technologies claim that they are integral to environmental sustainability, as they are considered to be a solution to a plethora of environmental problems in agriculture. This thesis interrogates those claims through three different studies that contribute to the disciplines of Science and Technology Studies, Critical Data Studies, and Critical Food Studies. The first study considers how DA technologies fit into discourses of sustainable agriculture in the Canadian policy and media landscape. After conducting a discourse analysis, an *ideology of optimization* became evident. This ideology works to communicate that environmental sustainability needs to and will be optimized using DA technologies. In many ways, this ideology solidifies already dominant paradigms of industrial and productivist agriculture. The second study interrogates the claim that private investment funding in ag-tech will strengthen Canada's capacity to combat climate change. Through interviews with ag-tech actors in Canada who identify as technology designers, entrepreneurs, and, importantly, funders, such as venture capitalists, I found that ag-tech actors' capacity to imagine sustainable food systems is heavily shaped by their social contexts and cognitive processes, and that they tend to equate the adoption of digital technologies with the practice of sustainability. The third article focuses on the ways in which the most powerful agri-businesses create value, both economic and otherwise, from agricultural big data. Using the lens of assetization, we examined key corporate documents. Our results identify three main strategies of assetization: securing relationships and dependence, price-setting and data sharing, and product development and targeted marketing.

The strategies have socio-ecological implications, as they indicate that asymmetrical power relations in the agri-food system that favour corporations are being reproduced.

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Preface

This thesis consists of three stand-alone papers that have been prepared for publication in academic journals. Although the papers relate conceptually and are broadly contribute to knowledge on the topic of digital agriculture, they are not necessarily meant to be read in order, and they do not directly build onto another. They use distinct research methods and theoretical frameworks.

Chapter 1, *Optimizing Stewardship of the Land? Digital Agriculture and the Ideology of Optimization in Canadian Policy and Media Discourse*, was researched and written solely by myself, Sarah Marquis. It has been submitted for publication at *Canadian Food Studies*. At the time of the submission of this thesis (October 2024), it has been accepted with minor revisions, and those revisions are currently in the process of being completed. Chapter 2, *Seeding Capital: Tracing the Limitations of Ag-Tech Actors' Imaginative Capacities to Facilitate Environmental Transformation*, was also researched and solely written by myself. It has been submitted to *Agriculture and Human Values* and is in the preliminary processes of peer review. Prior to its submission at that journal, I workshopped this paper with the Science and Technology Studies Food and Agriculture Network, and their deep engagement with the work, which I am deeply grateful for, shaped the article that it is today. Chapter 3, *Harvesting value: Corporate strategies of data assetization in agriculture and their socio-ecological implications*, was a collaborative effort between Dr. Sarah Hackfort, myself and my supervisor, Dr. Kelly Bronson. This article was published in *Big Data and Society* in 2024. This paper was initially conceived by Dr. Hackfort and Dr. Bronson. I was brought on in the preliminary stages of the work. I helped develop the literature review and research design and I, along with Dr. Hackfort, collaborated on both the data collection and analysis. Dr. Hackfort drafted the first iteration of the article, while Dr. Bronson and I contributed significantly to the editing and re-drafting of subsequent iterations. The article also went through the peer review process at *Big Data and Society* and benefited immensely from the anonymous peer reviewers and the editorial team at the journal.

Research Ethics Note: All interviewees for Chapter 2 gave their informed consent before participating in this study. The research was conducted in accordance with research protocol S-05-23-9273 approved by the Office of Research Ethics and Integrity at the University of Ottawa.

Introduction: Optimizing Stewardship of the Land? Exploring the Environmental Sustainability Dimensions of Digital Agriculture in Canada

Digital agriculture (DA) is understood as an approach to agriculture that is high-tech and data intensive. DA technologies include robotic machinery, big data applications, drones and remote sensing technologies that are all beginning to play a role on larger scale industrialized farms in North America (Rotz et al., 2019). The process of digitization in agriculture has been uneven and faltering, though the farms of the future are envisioned to be highly automated environments wherein farmers have deferred much of their decision-making to 'smart' machines that analyze data to make the most optimal decision possible (Lioutas et al., 2019; Jouanjean, 2019). As the socio-technical system of DA emerges, many social scientists have questioned the impacts of digitization, specifically its impacts on relationships of power, with respect to farm workers (Doggett et al., 2024), the organization of labour (Legun & Burch, 2021), data privacy (Wiseman et al., 2019) and data assetization (Hackfort et al., 2024). Meanwhile, proponents of the approach welcome it as a long-awaited revolution in agriculture (Basso & Antle, 2020; Klerkx et al., 2019). Ostensibly, the age of DA will allow farmers to say goodbye to labour intensive agriculture, and welcome more manageable work environments all facilitated by interoperable technologies connected through The Internet of Things, with seemingly infinite cloud computing abilities. Crucially, proponents of DA envision it as central in certain trajectories of environmental sustainability, as it is considered to be a solution to a plethora of environmental problems in agriculture (Balafoutis et al., 2017).

The three papers submitted as part of this thesis all focus in different ways on the relationship between DA and environmental sustainability. They all interrogate the role of DA in the food system, and the ways in which these technologies may impact crucial relationships of power that are influencing the success and feasibility of sustainability transformations. This introduction begins with a positionality statement, and will then provide relevant context for the papers, explaining the emergence of DA and unpacking the contested discourses of environmental sustainability. And though the entire project of the PhD was interdisciplinary in nature, the three papers build from concepts that have emerged from three bodies of literature: Science and Technology Studies, Critical Data Studies and Critical Food Studies. Following a short introduction of these bodies of literature, I will briefly introduce the papers.

Positionality Statement

Before I contextualize the problem, it is important for me as a scholar to position myself in relation to this research. I became interested in the relationship between the food system and the climate crisis one decade ago after having finished an undergraduate degree in Environmental Science from Queen's University. After the completion of my degree, I was working in the food services industry as a banquet server at the Ritz-Carlton in downtown Toronto. I would also spend my spare time volunteering for the Yonge Street Mission Food Bank located in a less affluent area of the city. The Ritz-Carlton is one of the most expensive luxury hotels in Toronto that has a reputation for serving a wealthy and ultra-wealthy demographic. In my time as a banquet server, my serving team and I would be asked to throw away immense amounts of freshly made food that had been prepared in surplus for various events like weddings or conferences. Then, the next day, I would work a volunteer shift at the food bank, serving food insecure people and families who struggled to access fresh food due to, usually, income constraints. The combined experiences marked the first time I came face-to-face with the impact of power inequities in the Canadian food system.

Eventually, I left these positions to pursue a Master's degree at the University of Guelph, a university known for its focus on food and agriculture. It was there that I learned that food waste, food insecurity, and climate change were all interconnected problems which were products of a colonial and capitalist food system. I turned my scholarly attention towards digital technology during this time, and I began to question and critique the role that DA technologies played in these power inequities, especially at the point of food production: the farm. I wrote a Master's thesis about datafication in agriculture, and that work led me to this PhD project which continues to apply a critical lens to the nexus of technology, environmental justice and power in agriculture. Furthermore, in non-academic spaces, I am a climate activist in the city of Ottawa with an organization called Climate Justice Ottawa. Climate Justice Ottawa advocates for "alternatives to a carbon-centric economy that addresses the interests of marginalized communities" (Climate Justice Ottawa, n. d.). I am committed to attending to the root causes of climate injustice through my activism *and* my research.

I explain the path that I took to come to this PhD because personal life-history is relevant to my positionality and the ways that I engage with this research (Chiseri-Strater, 1996). My worldview contains within in ontological and epistemological assumptions that are also shaped by my "political allegiance, religious faith, gender, sexuality, historical and geographical location, ethnicity, race, social class, and status, (dis) abilities and so on" (Holmes, 2020, p. 2). These assumptions and worldviews influence how the research is conducted, how data is analyzed and how findings and results are reported in myriad ways. I am a cis-gendered, English-speaking white woman and a settler who has conducted this research and written this thesis on the unceded and unsurrended territory of the Omamìwìnini Anishnàbeg (Algonquin) Nation. I also recognize that the subject of this thesis, the Canadian agricultural system, has been built on a foundation of colonial violence and genocide (Settee & Shukla, 2021). However, as a white settler, I benefit from these structures of white supremacy. For example, in Chapter 2, I discuss having gathered data from ag-tech actors, such as entrepreneurs and venture capitalists. I believe that elements of my positionality (such as my whiteness and my ability to speak English) granted me particular access to these communities with whom I share these identity traits. I share my explicit positionality with regards to this research to offer the reader the space to make a "better-informed judgement as to the researcher's influence on the research process and how 'truthful' they feel the research data is" (Holmes, 2020, p. 3).

The Emergence of Industrialized Agriculture

To further contextualize this research, it is critical to place the emergence of DA technologies within a longer history through which industrial agriculture has evolved. Food studies scholars Friedmann & McMichael (1989) trace transformations in the food system back to the colonial era in which the British Empire held much more global power. In the authors' scholarship on food regimes, the first global food regime was dominant between 1870 and 1930, and was defined by the importation of livestock and grain from settler states to colonial rulers. After the first and second world wars, the second food regime emerged, wherein the United States was a more dominant global superpower, and this period was defined by the use of food as a strategic resource by the US to gain power in the Cold War (Carolan, 2012). Characteristics of a third food regime are still emerging – but many food studies scholars have discerned that it is defined by corporate consolidation, financialization and neoliberalism (McMichael, 2009). In this third food regime, agri-businesses are more powerful than a single nation-state, and they are motivated to gain more and more access to land, nature, labour and capital (Carolan, 2012; Clapp, 2020). Corporate mergers have continued this trend of corporate consolidation of power (Clapp, 2020).

In a more geographically focused perspective, Fitzgerald's (2003) work argues that the American industrial logic for agriculture emerged in the 1920's. A so-called industrial web of actors was coming into being – these actors included farmers, materials, product, markets and resources. It was within this ecosystem that farmers were encouraged to grow the size of their farms and separate livestock from the farmland itself, which enabled larger and larger economies of scale. (Fitzgerald, 2003; Weis, 2022). This 'modernization' process was encouraged by actors throughout the sector, and key elements of this transition included new technological innovations and the quantification and mechanization that these technological developments facilitated. It is critical to understand the relationship between agricultural industrialization and environmental degradation (Weis, 2022). Researchers in geography, sociology and food studies have argued that "the environmental damage associated with the global industrial food system is an outgrowth of the capitalist expansion of agriculture" (Clapp & Scott, 2018, p. 2). For example, the shift from seed-saving practices to the commodification of hybrid and genetically modified seeds has shifted power away from subsistence farmers and into the hands of seed and input companies. Rising global and domestic food insecurity, labour shortages and the increasing cost of farm inputs has led to a cost-price squeeze on farmers – a phenomenon in which the technological machinery and inputs required for modern agriculture are getting more costly, while the financial renumeration for farm products is decreasing (Wiebe, 2022). This industrial approach to agriculture was exported globally during what is called the Green Revolution (Clapp, 2020). There is a widespread scholarly understanding that these developments were intrinsically tied to environmental degradation through the loss of plant diversity, the depletion of soil health, water scarcity and greenhouse gas emissions associated with industrial practices such as monocropping and the use of large machinery. Clapp, among others (notably Howard, (2021)) has also done extensive work to demonstrate that the development of oligopolies and monopolies in the agricultural input, machinery and seed industries has shaped both market dynamics and policy agendas on a global level (Clapp & Scott, 2018). As one example, this shows that the world's largest agribusinesses lobby state governments to advocate for less restrictive regulations – from glyphosate use to labelling of genetically modified foods (Clapp & Scott, 2018). This policy influence has direct consequences for the environment.

The same concentration of agribusinesses tied to the industrialization of agriculture and related environmental and social crises are now behind the emergence of DA technologies is happening within this context. Signals from the international policy sector suggest that resources are being put towards the global uptake of DA in response to these many problems (Lajoie-O'Malley, 2020), mostly because proponents of these technologies claim that they will enable farmers to reduce and optimize input use, reduce labour and streamline agricultural production. This process of digitization has been labelled the 'fourth agricultural revolution' or 'Agriculture 4.0' (Rose & Chilvers, 2018) and is often framed as inevitable. Crucially, however, there is (so far) little evidence that there are widespread environmental benefits tied to the use of these technologies (Basso & Antle, 2020).

The Many Faces of Sustainability in Agriculture

Before delving into the nuanced relationship between DA and environmental sustainability, it's necessary to explore the complexities of the concept of sustainability itself. Definitions of sustainability "tend to be cast in terms of living within the finite limits of the planet, of meeting needs without compromising the ability of future generations to meet their needs and of integrating environment and development." (McNaghten & Urry, 1998, p. 215; see also: Agyeman, 2003). Earth system scientists have brought forward the concept of 'planetary boundaries', "within which we expect that humanity can operate safely" (Rockstrom et al., 2009, p. 1). These boundaries include (but are not limited to) climate change, biosphere integrity, land system change and biogeochemical flows. Richardson et al. (2023) found that humanity has transgressed six of the nine specified boundaries. Other scholars have critiqued this framework, arguing that 'social boundaries' must be considered as well (Leach et al., 2013). Scoones (2016) has explored the different ways that sustainability transformations play out through 'technology-led', 'market-led', 'state-led' or 'citizen-led' processes. Considering the relationship between sustainability and techno-science, Benessia & Funtowic (2015) ask: "What do we want to sustain and for whom?" Though the possibilities for sustainability might be more complicated than this basic question (see: Fraser et al., 2016), two important visions of sustainable agriculture have emerged in response to environmental crises: sustainable intensification and agroecology. This is not to say that these two agricultural paradigms are the only ones or are in complete opposition to one another; they are simply the ones garnering the most attention – from public policy-makers to scholars to grassroots activists.

Since the advent of the 21st century, there has been a focus on how to achieve sustainable agriculture. As Garnett writes: “The food ‘problem’ has become a global obsession” (2014, p. 10). This was only exacerbated by the 2008 financial crisis and subsequent increase in global food prices (Levidow, 2018). Then, in the late 2000’s, the Food and Agriculture Organization of the United Nations (FAO) High-Level Expert’s Forum “How to feed the world in 2050” stated that food production needed to increase by 70% by the year 2050 (FAO, 2009). In this context, ‘sustainable intensification’ emerged as an ideal to strive for: a purported transformation of the food system in which enough food would be produced to feed a growing population and reductions in environmental impact would be prioritized (Thompson, 2018). According to Garnett et al. (2013), sustainable intensification is focused on increasing production; and this increase in production must be attained through higher yields due to the fact that increasing land under agricultural production comes with a steep environmental cost. The possibility of sustainable intensification has been hotly debated by scholars in food studies, geography and beyond. Horlings et al. (2011) describe it as ‘weak modernisation’: a modernisation of the food system which is productivity-oriented, export-oriented and in which power is concentrated within the hands of the same actors who have it now: multinationals and large retailers. According to many scholars (see: Godfray, 2015), sustainable intensification squarely fits within productivist or neo-productivist categories of agricultural production, meaning it still operates on industrial scales and focuses on output quantity and increased productivity above all else. Sustainable intensification works “within the prevailing capitalist and carbon-based economy”

(Horlings et al., 2011, pg. 445). This productivist orientation differentiates sustainable intensification from other agricultural paradigms, such as agroecology.

Agroecology, on the other hand, strives to “maximize diversity through holistic systems that create long-term fertility” (Constance, 2018, p. 4). There are many different manifestations of agroecology, including regenerative agriculture, permaculture, and organic farming. Proponents of agroecology recognize that it must have a political economy focus in order to resist hegemonic agricultural systems. They also question the FAO’s claim that food production is required to increase to such a high degree, as it is understood that hunger is an issue of access, distribution and income rather than an issue of low production (Bernard & Lux, 2017). Gliessman, one of the most well-known Western thinkers on agroecology, contends that the definition of agroecology has shifted throughout the years, and it is focused not only on ecological diversity but the social and political systems that determine how food is grown, how it is distributed, and how food mediates power (2018).

La Via Campesina, a global peasant farmers movement advocating for agroecology, has rejected the paradigm of SI on the grounds that it is a continuation of the Green Revolution, which does not contribute to food security or food sovereignty, which entails the right of communities to control their own food systems (LVC, 2003):

> *“…raising yield per hectare through production intensification only increases the income for corporations, financial market speculators, and large landholding farmers [...]*

> *Increasingly, peasant and smallholder family farmers have to produce crops for the commodity market and not for local and regional food systems."* (LVC, 2014, p. 2).

Because the concept of agricultural environmental sustainability is so contested, and also so central to this thesis, it is important for me to clarify the working model of sustainable agriculture I leverage in this project. I am not a farmer but I tend to align myself with the stance of La Via Campesina activists and researchers, as the work that I do attends to questions of justice, power and sovereignty, and I take the position that these are linked inextricably to ecological impacts. Furthermore, I believe that advocacy for local food production systems, and on behalf of the peasant and small-scale farmers who are integral to these systems, is a large part of the necessary route to food sovereignty. However, when discussing environmental sustainability in agriculture, it is important for me not to reproduce the discursive binary between industrial and small-scale agroecological agriculture. Binary thinking around food systems is reductionist and unhelpful, and what is likely needed is a diversity of farming environments that includes large-scale farms. Beus & Dunlap suggest that it might be more fruitful to consider agricultural practices on a continuum rather than categorizing agricultural environments as either one or the other (1990).

In sum, the model of sustainable agriculture within which I ground my research is a vision wherein the roots of worsening crises might be attended to through the redistribution of wealth and power, and through both food sovereignty (Desmarais, 2022, LCV, 2003; Wittman, 2011) *and* technological sovereignty (the concept that communities should have the right to appropriate technologies, and that they should have control over the socio-technical systems that they are a part of (Montenegro de Wit, 2021)). Agroecology is more closely aligned to this vision because not only does it entail a certain set of diverse practices, but it is also a social movement that centers social justice and challenges unequal relationships of power. It is as much about ensuring the stability of ecosystem services in an agricultural environment as it is about improving local food security and "counter[ing] macro-scale political and economic phenomena [and striving] for social justice" (Isaac et al., 2018). Agroecology is an example of what Horlings et al. call 'strong ecological modernisation', in which there is more synergy between humans and the natural environment; it is locally embedded within communities as opposed to being globalized; and power is decentralized and distributed throughout local and regional actors (2011).

Agroecology in Practice and Policy

It is also important to be specific about the practices involved in agroecology, in part because of an observation that, like 'regenerative agriculture' the term is being co-opted by agribusinesses, turned into marketing buzzwords, and used to greenwash industrial agricultural practices (Wilson et al. 2024). Agroecology also varies widely between different contexts and localities. Agroecology, as a set of practices, aims to "improve agricultural systems by mimicking and enhancing natural processes of the ecosystem" (Bernard & Lux, 2017). Farmers who engage in agroecological practices focus on maintaining soil health by, for example, reducing external inputs, intercropping, and cultivating legumes (as they enrich the soil and fix nitrogen). It also calls for more attention to be paid towards water conservation and agro-biodiversity (Laforge et al., 2021). This could entail the creation of micro-habitats, integrated pest management and the incorporation of agroforestry into the system (Bernard & Lux, 2017). However, agroecological practices are, by definition, context specific and localized, so it is important not to prescribe what agroecology could look like in all agricultural environments. The elements of soil health and agrobiodiversity are simply key aspects that are attended to in agroecological environments.

There are many creative policies that would expand the prevalence and prominence of agroecological systems in Canada. Lowitt et al. explain how a basic income guarantee would empower both farmers *and* consumers, allowing increases in food access, while giving farmers and food producers the financial space they need to experiment with production practices or invest in agroecological practices (2024). The National Farmers Union advocates for farmers to have access to *independent* agrologists, extension service providers and soil specialists so that they do not need to depend on agrologists who represent input companies and who prioritize the best interests of agribusinesses. Independent expertise could allow farmers the autonomy to use less inputs, and adopt more agroecological practices (NFU, 2019). The National Farmers Union also suggests a 2% tax on fertilizer companies and a public and independent inquiry into the oligopolic practices of the four main fertilizer companies operational in North America: Nutrien, CF Industries, Koch Fertilizer and Yara (Qualman & the National Farmers Union, 2022). Ultimately, my definition of sustainability comes from my positionality (see above) and my overall objective in this research to promote interventions such as these which would address unsustainable power dynamics in agriculture and the food system at large, would contribute to food sovereignty across Canada.

The Role of Digital Agriculture in Sustainable Agriculture

The role of DA in sustainability has been considered by many scholars in diverse disciplines. However, the mechanisms through which DA is said to enhance sustainability are embodied in the paradigm of sustainable intensification. As Miles argues, a key discursive argument for DA is the idea that it will enable farmers to increase production, while decreasing environmental impact (2019). One of the early perspectives on precision agriculture from Gebbers & Adamchuck outline the three goals of DA: “First, to optimize the use of available resources to increase the profitability and sustainability of agricultural operations. Second, to reduce negative environmental impact. Third, to improve the quality of the work environment and the social aspect of farming, ranching and relevant professions.” (2010, p. 828-829). Gebbers & Adamchuck go on to explain how DA will contribute to “food security in a constantly changing world.” (2010, p. 830) This is a very common line of logic among proponents of DA, and it is consistent with the underlying elements of sustainable intensification.

Lindblom et al. (2017) have a more nuanced approach. The authors acknowledge that DA could play an important role in the sustainable intensification of agriculture, however, they contend that a participatory approach to technology design would be necessary for these developments to occur. While it is much more usual to find DA applications on large scale farms (Miles, 2019; Finger, 2019), precision conservation (Capmourteres et al., 2018) and precision agroecology (Duff et al., 2021) have also been suggested as ways to integrate DA into sustainable agriculture. Many scholars have and continue to do research on ways in which technologies can be used to shift power relationships within the agricultural system to become more equitable (DiSalvo, 2014). A recent paper by Ditzler & Driessen concluded that automation needs to be rethought for agroecological contexts, it should not be considered as “a blueprint for replacing humans, but making room for analogue and hybrid forms of agricultural work.” (2022, p. 1) However, though there might be applications of DA that enable equitable distribution of power, the vast majority of its applications are in service of large-scale conventional agriculture operations. Bronson concludes "the current trajectory for digital agriculture is one which supports the continuation of large-scale, low-value crop farming amended for more judicious use of chemicals and water." (2020, p. 336) In short, this perspective states that DA is *sustaining* the status quo.

Digital Agriculture and Critical Social Science

Though technical literature on DA has been growing for a few decades (Finger et al., 2019), the critical social scientific work on this topic has begun to proliferate as well. A seminal 1996 paper by Wolf & Buttel argues that the expansion of DA will result in the continued 'industrial intensification of agriculture'. Wolfert et al. (2017) carried out a significant systematic review in the scholarship of DA and made the prediction, informed by the literature, that the future of DA could go in two separate directions – one in which technical systems are closed and benefit only a few entities in the sector, or open, collaborative systems that could enable farmer and stakeholder autonomy. It is implied that sustainable agriculture would only be possible through the latter outcome (see also: Bronson & Knezevic, 2016; Rotz et al., 2019). Klerkx et al. (2019) conducted a review solely on the social science literature to identify current strands of research in different social science fields, but also identified understudied areas that could be taken on in the future. These authors highlight the need to continue to research how DA enables or disables more sustainable agricultural systems, such as organic farming, agroecology, regenerative agriculture, and urban agriculture. Similarly, Rotz et al. (2019), in a review that focused on the politics of DA, found that the available literature identified tensions between the use of DA technologies and sustainable approaches to land use in agriculture. Notably, many reviews concerning DA, for example Weersink et al. (2018), highlight data governance and data ownership issues as major barriers to the widespread adoption of DA technologies. Questions of data ownership will always be relevant to the study of DA and its relationship to power. Throughout this section I will discuss the three bodies of literature that have helped inform the research design for the three papers that make up this thesis: Science and Technology Studies, Critical Data Studies, and Critical Food Studies.

Science and Technology Studies

STS explores relationships of power between science and society and interrogates how scientific knowledge and technologies are produced through specific social and political processes (Sismondo, 2009). Key topics of STS include scientific expertise, the production of scientific knowledge, the political dimensions of technological artifacts, and public understandings of science and technology (Sismondo, 2009). Through STS we understand that science and technology are intrinsically related because "societies make themselves not only through knowledge but also through the design, construction and use of material devices and infrastructures" (Felt et al., 2017, p. 19). Agri-food has always been a compelling site of study for STS scholars; one of the classic examples is Langdon Winner's consideration of the mechanical tomato harvester in his seminal article *Do Artifacts Have Politics?* He explored how this automated machine had various social and political consequences: it led to increased profits and job losses, but also changed the materiality of the tomato itself: the proliferation of this device led to "tomatoes that are hardier, sturdier, and less tasty" (1980, p. 126). One key example of how technology has become entrenched in productivist agriculture is the concept of the 'technological treadmill,' in which on-farm adoption of new technologies leads to short-term profitability, but as more and more farmers adopt these new technologies, supply increases and prices eventually drop. This pattern incentivizes farmers to adopt newer and newer technologies, continuously in search of short-term profitability (Levins & Cochrane, 1996). This is only one such way that technology and the productivist model of agriculture co-produce one another in agriculture. STS literature has also focused on a host of other agriculture-related topics like food safety risks (Burch, 2019), chemical inputs like glyphosate (Adams, 2023), and genetic engineering of seeds (Bronson, 2015).

STS has also been a useful lens through which to consider the emergence of digital technologies in agriculture. Legun et al., for example, explore the shifts in agricultural labour relations and agricultural expertise that have come with the introduction of artificial intelligence and other automated technologies on the farm (2023). The socio-technical imaginary, a key concept in STS, has also been deployed in myriad ways in the context of DA. Socio-technical imaginaries of DA held by farmers, technologists and other actors in the agri-food ecosystem can have profound impacts throughout the system (Bronson, 2022). Guthman, for example, explores the visions of agriculture held by Silicon Valley entrepreneurs who are excitedly seeking investment in cellular agriculture and alternative protein start-ups (2022). Gugganig explores the ways in which these socio-technical imaginaries in vertical farming are contested and borrowed from other sectors (2024). This work also explores how Big Tech and the world of Silicon Valley has come to make itself known in the agri-food space, with various socio-political consequences (Guthman, 2024). All this to say that STS remains a relevant discipline through which to consider DA, and STS work in agri-food has deeply informed the three papers I present in this thesis.

Critical Data Studies

Critical data studies has also been a crucial lens through which to consider DA, as DA technologies generate vast amounts of environmental big data, whose use is, as yet, mostly un-regulated. Scholarly conceptions about big data began around the time boyd & Crawford (2012) published a series of provocations attending to the so-called 'Big Data Revolution'. In their work, they implore critical social scientists to pursue research agendas about how the phenomenon of big data has the potential to shift epistemologies in every discipline, how data's assumed objectivity could impact marginalized populations, and how context is undervalued in new industries founded on the collection and analysis of big data. The *Big Data and Society* journal was established in 2014, and a special issue marked the emergence of the CDS discipline whose main goal is to question the power structures enabling and enabled by big data assemblages (Iliadis & Russo, 2016). Other sub-disciplines, like Critical Algorithm Studies, have arisen in response to this call to action. Seaver (2017), Burrel & Fourcade (2021), Alkhatib (2021) and Amoore (2020) all attend to the impact big data assemblages, namely algorithms, have on relationships of power. Zuboff's *The Age of Surveillance Capitalism* has documented the rise of social media and advertising companies like Facebook and Google that rely predominantly on the collection and analysis of personal data to generate profit (2019).

There is also emerging scholarship on the wider role that farm-level big data is playing in the North American agri-food system. This is well laid out by scholars such as Fraser (2018; 2021), Bronson & Knezevic (2016), Bronson (2022), and Wiseman et al. (2019). For example, Farmer's Edge, a Canadian DA company, offers a data collection service using weather stations, satellites, and sensors (installed directly onto farm machinery). Farm-level big data is collected, aggregated and analyzed using in-house data analytics services to provide farmer users with recommendations for optimal planting and harvest decisions (Bronson et al., 2022). The implications of this data generation and collection are far-reaching, and, according to some, extremely detrimental to possibilities for sustainable agriculture. Fraser (2018) refers to farm-level data collection by private companies as a data grab, and simply an extension of capital accumulation. He states: “the data grab will amplify the global land grab” (p. 2). Duncan et al. (2022) argue that DA technologies are contributing to land financialization, reducing farmer autonomy and access to land. Critical data studies has been integral to the research design of this thesis, especially for the third paper: *Harvesting value: Corporate strategies of data assetization in agriculture and their socio-ecological implications (*written with Sarah Hackfort and Kelly Bronson).

Critical Food Studies

Lastly, Critical Food Studies has informed this work from beginning to end. Critical food studies is interdisciplinary, considering food and food production from schools of thought in anthropology, political economy, gender studies, and environmental studies, to name a few. Critical food studies is helpful for this work because it offers critical perspectives that examine patterns of social inequalities and structures of political power that contribute to overlapping problems in agri-food, from the farm crisis to eating disorders, from food insecurity to biodiversity loss (Koç et al., 2022). A significant site of scholarship in food studies is the attendance to and consideration of corporate consolidation of wealth and power (Clapp, 2022). The concentration is happening at multiple levels of the food system and has wide-reaching impacts for marginalized populations. Critical food scholars have also explored the Canadian food system in depth, demonstrating policy failures that have led to the growing gap between large and small farms, the human rights abuses of migrant farm workers, and rising food insecurity throughout the country. With regards to DA, there are many ways in which Critical Food Studies can provide a useful set of tools to critique and understand the implications of these technologies. Scholars are observing the ways in which large agri-food corporations are repositioning themselves in the model of successful technology companies like Google (Bronson & Sengers, 2022). The technologies themselves are also affects workers' relationships to farm labour, and the relationship between farm operators and migrant farm workers (Dogget et al., 2024; Rotz et al., 2019). Rotz et al. (2019) has found that economic pressures on farmers are driving farmers to try to "minimize labour costs by any means possible" (p. 4). This is contributing to the uptake of automatic and robotic technologies. In short, Critical Food Studies calls attention to the political, economic and ecological dimensions of food production and consumption and remains a crucial tool by which to examine agricultural digitization.

Thesis Overview

The following three papers have been submitted together for the requirements of my PhD in Environmental Sustainability at the Institute of the Environment at the University of Ottawa. They are three standalone papers, written not in the style of a monograph dissertation but to meet the requirements of the respective journals that I have submitted them to for publication. The first paper considers how DA technologies fit into discourses of sustainable agriculture in the Canadian policy and media landscape. What became evident through this work is that there exists an *ideology of optimization*, which works to communicate that environmental sustainability needs to and will be optimized using DA technologies. This paper looks at the ways that the 2020 fertilizer target uses this ideology of optimization inadvertently to keep current systems of fertilizer use in place, further solidifying the industrial and productivist paradigm of agriculture in Canada. The paper furthers theoretical thinking on optimization, which has emerged from Critical Data Studies and STS. The paper also argues that optimization as a theoretical concept should be considered more seriously by Critical Food Studies scholars, as so much of the Canadian agricultural industry operates according to logics of optimization. These logics have profound impacts on human and non-human entities that are part of the food system. This paper has been submitted to *Canadian Food Studies* and has been accepted with minor revisions (which are in the process of being completed now (October 2024)).

The second paper is an exploration of the perspectives of various ag-tech actors, specifically venture capitalists, entrepreneurs and technologists to consider how they imagine future paradigms of sustainable agriculture. Throughout the research process, I conducted 18 interviews with ag-tech actors in Canada, and I found that their imaginations of sustainable agriculture are considerably limited by the context of ag-tech entrepreneurialism. For this project, I used Milkoreit's (2017) theory of imagination, which considers imagination as a process that is affected by actors' cognitive capacities and social contexts. I found that ag-tech actors in Canada, in their imaginations of the future, tend to subjugate environmental sustainability to financial gain and entrepreneurial success. Furthermore, these actors considered DA *to be* sustainable agriculture in and of itself. The narrative of digital and sustainable being one and the same works, then, to undermine alternative, low-tech visions of agriculture that might be more local, more community-oriented, and less input-intensive. This finding is crucial for scholars considering the STS dimensions of agriculture and the role of DA in sustainable agriculture. I also build on Milkoreit's theory of imagination and encourage STS scholars to consider not just the socio-technical imaginary, but the imagination as a process that can be either hindered or facilitated, as a capacity that can be grown or diminished. The paper ends by considering how to increase the imaginative capacities of those with less structural power than the ag-tech actors I studied. This paper has been submitted to *Agriculture and Human Values* and is in the process of peer review.

The third paper, recently published in *Big Data and Society,* considers the strategies and methods ag-tech companies and agribusinesses use to *assetize* agricultural data that is generated by DA. We found that large agribusinesses across the world use similar strategies to assetize agricultural data and transform it into financial value: they secure relationships of dependence between farmers and agri-businesses, data are used to set prices and are sold and shared to third parties, and data are used to develop new products and target marketing to users. This work was particularly novel because it considered the process of assetization of a previously understudied artifact of technoscientific capitalism: agricultural big data. STS scholars have recently begun to seek to understand how value and valuation are socially organized and co-produced with techno-economic processes, practices and knowledge (Birch & Muniesa, 2020). And therefore, this research brought STS, Critical Data Studies and Critical Food Studies into conversation with one another. We then considered the social, ecological and political implications of these assetization practices. Since agricultural data play such a crucial role in the concentration of corporate power in the food system in North America and beyond, we call for the broader restriction of oligopoly in food and farming. We also recognize the need for the governance and regulation of agricultural big data that would benefit not only farmers, but other actors in the food system who are affected by data assetization. This paper was a collaborative effort all the way through, and I contributed specifically by doing a considerable amount of the data collection and analysis. After the first draft was written by Sarah Hackfort, I contributed substantially to writing of the subsequent drafts and the editorial work as the paper made its way through peer review. I also contributed to the knowledge mobilization of the project through writing and publishing a blog post about the paper for the journal. I am very grateful to my co-authors Sarah Hackfort and Kelly Bronson, for their support and guidance throughout this project.

Chapter 1:

Optimizing Stewardship of the Land? Digital Agriculture and the Ideology of Optimization in Canadian Policy and Media Discourse

Author:

Sarah Marquis

Abstract

This research considers the ways in which digital agriculture (DA) technologies (like robotic machinery, big data applications, farm management software platforms and drones) fit into discourses of sustainable agriculture in the Canadian political and media landscape. To undertake this research, I conducted a discourse analysis of relevant government and media materials published between 2016 and 2022. What became evident was an *ideology of optimization,* which works to communicate that environmental sustainability needs to and will be optimized using DA technologies. I then consider how these findings are related to the federal fertilizer emissions reduction target, aiming to reduce emissions arising from fertilizer application in agricultural contexts by 30% below 2020 levels by 2030. I argue that discourse regarding this target deploys the ideology of optimization to keep current systems of fertilizer use in place, solidifying further the industrial and productivist paradigm of agriculture in Canada.

Keywords: Digital agriculture, optimization, sustainable agriculture, nitrogen fertilizer

Introduction

The Canadian agricultural system is facing serious problems; it is both a contributor to climate change and other environmental problems, while simultaneously being heavily impacted by the consequences of these crises (Clapp et al., 2018). Globally, it is estimated that between 20-35% of anthropogenic greenhouse gas (GHG) emissions are from the agricultural sector (Clapp et al., 2018). In Canada, the National Inventory Report states that the Canadian agricultural sector currently contributes 8-10% of Canada's GHG emissions. Emissions of all three major GHGs (carbon dioxide, methane and nitrous oxide) are emitted through agricultural processes - with enteric fermentation from livestock production being a major contributor, and the release of nitrous oxide from synthetic fertilizer use being another (Environment and Climate Change Canada, 2023). Meanwhile, climate change is wreaking havoc on the agricultural sector across the country. The 2023 growing season has been affected by severe drought in Alberta, Saskatchewan and Manitoba (Goodwein & Melgar, 2023), and British Columbia suffered severe droughts in 2021, followed by flooding events that affected hundreds of farms provincewide (Schmunk, 2021). With rising emissions, these impacts will likely continue and become worse (Kornhuber et al., 2023).

Many people believe that the adoption of digital technologies in agriculture may help address the sector's sustainability challenges. Digital agriculture (DA) can mean many things, but it ultimately involves the application of digital technologies - from sensors, drones and robotics to farm management software applications - that support farmer decision making. This paper assesses policy and media texts relating DA and sustainability in Canadian agriculture. Methods consist of a discourse analysis of relevant government and media materials published between 2016 and 2022 which refer to agricultural sustainability: the dataset includes relevant government reports, government media releases, and media articles from national and regional newspapers published in Canada. Discourse analysis of these texts revealed an *ideology of optimization*, which does cultural work along three axes: firstly, the discourse communicates that environmental sustainability needs to be and will be optimized using DA. Secondly, the discourse forwards an argument that environmental sustainability will indirectly result via the "optimization" of other farm variables, notably profitability. Finally, the discourse embeds an argument that "optimization" will occur through the quantification and datafication of agricultural environments, a process that necessitates digital technologies. After the results of the textual analysis are presented, the findings are related to the fertilizer emissions reduction target announced by the Canadian federal government in 2020, which aims to reduce emissions arising from fertilizer application. This article demonstrates that discourse about the fertilizer emissions reduction target deploys the ideology of optimization to keep current systems of fertilizer use in place, further solidifying the industrial and productivist paradigm of agriculture in Canada. Furthermore, the article contends that the concept of optimization could be useful to critical food studies scholars, who for years have critiqued this productivist agricultural paradigm for its social and environmental consequences (Buttel, 2006). Lastly, the article concludes that critical data studies scholars who have critically assessed optimization in relation to digital platforms might find agriculture a useful site of study.

Background: The Role of Digital Technology in Canadian Climate and Agricultural Policy

Canada's federal response to climate change began in a serious way when it signed onto the Paris Agreement in 2016, and committed to achieve 'net-zero' emissions by 2050 (Vinco et al., 2023). This response has resulted in many different federal strategies, policies and new pieces of legislation. However, for the most part, the focus of legislation has been on the oil and gas sector, transportation, buildings and electricity (Vinco et al., 2023). At the same time, the federal government has established various programs to encourage more sustainable practices in the agricultural sector. For example, the Canadian Agricultural Partnership has recently evolved into the Sustainable Canadian Agricultural Partnership, which signifies Canada's desire to create more agricultural policy that is focused not only on economic growth of the sector but also environmental sustainability (Agriculture and Agri-Food Canada, 2023). A focus within these recent policies is synthetic fertilizer use. While synthetic fertilizer boosts crop production, a global dependence on these inputs has led to contamination of surrounding bodies of water and the emission of a potent GHG, nitrous oxide (Smil, 2004). In 2021, Canadian crop production was estimated to have been responsible for 19.4MtCO2eq, and 14.8 MtCO2eq was sourced from the application of synthetic fertilizers in crop agriculture (Environment and Climate Change Canada, 2023). Furthermore, the emissions associated with synthetic fertilizers have increased by 60% since 2005, as fertilizer use rose by 71% in the last two decades alone (Environment and Climate Change Canada, 2020; Robinson, 2023).

In response to broader climate change issues and fertilizer-related environmental impacts, the Government of Canada released an environmental climate plan called 'A Healthy Environment and a Healthy Economy' in 2020 which included a national target to reduce GHG emissions arising from fertilizer application in agricultural contexts by 30% below 2020 levels by 2030

(Environment and Climate Change Canada, 2020). The government is adamant that the mandate is and will continue to be voluntary, yet it is clear in media articles about the target that farmers are on the defensive, and they worry about the ways that this target could be regulated and/or legislated such that they are affected negatively; novel fertilizer-related regulations could possibly affect their yields, and hence their profit margins (Anderson, 2022). DA is, in this context, promoted by industry, government, and agricultural extension experts as a mechanism to help farmer's reduce emissions. It is assumed by proponents that these technologies will play an ever-increasing role in farming in the Global North (Minority World) (Weersink et al., 2018), and that digitization will facilitate a purported transformation of the food system in which enough food would be produced to feed a growing population, and, simultaneously, environmental impact would be reduced dramatically (Garnett et al., 2013). DA is argued to enable sustainable practices by allowing for precise management and thus more judicious use of inputs like fertilizers and fuel (Balafoutis et al., 2017; Finger et al., 2019; Hebert, 2022).

To some, the precise DA approach represents a paradigm shift in food production (Weersink et al., 2018). Meanwhile, a growing number of social science researchers are pointing out the social and ethical limitations of DA (see Bronson & Knezevic, 2016; Carolan, 2023a; Carolan, 2017; Duncan et al., 2021; Klerkx et al., 2019; Montenegro de Wit & Canfield, 2024). Klerkx et al. (2019) conducted a review of this social science literature and identified the need for research that interrogates the link being made (or assumed) between DA and more ecologically sustainable agricultural systems, such as organic farming, agroecology, regenerative agriculture, and urban agriculture. Rotz et al. (2019) found that the available literature identified tensions between the use of DA technologies and sustainable approaches to land use in agriculture. Bronson (2022) found that in their current state, DA technologies contribute to a number of food system challenges, such as corporate concentration and productivist strategies that deepen environmental problems caused by agriculture (see also: Bronson & Knezevic, 2016). Wolfert et al. (2017) carried out a systematic review in the scholarship of DA and made the prediction, informed by the literature, that the future of DA may go in two separate directions – one in which technical systems are closed and benefit only a few entities in the sector, or open, collaborative systems that could enable farmer and stakeholder autonomy (See also: Bronson & Knezevic, 2016; Rotz et al., 2019). This paper adds to this academic debate by investigating how DA is discussed in relation to environmental sustainability within Canadian public and policy discourse.

Theoretical Framing and Methods

The primary method for this research is critical discourse analysis. Discourse, according to Jørgensen & Philips refers to the "particular way of talking about and understanding the world (or an aspect of the world)" (2002, p. 2). This 'particular way' shifts depending on the source of the language, and the audience consuming it. Discourse analysis is an attempt to interrogate representations of knowledge that are presented as if they are the objective truth. Discourses are systems of thought and demonstrations of power, expressed through different mediums, but often analyzed through text or speech (Van Dijk, 2013). Discourses are underpinned by ideologies, which are, according to Marx, the process "through which dominant ideas within a given society reflect the interests of a ruling class" (1977, as cited in Stoddart, 2007, p. 191). Ideology represents ways of thinking in which certain forms of social organization are represented as inevitable and rational (Stoddart, 2007). The 'critical' piece of critical discourse analysis aims to uncover the ways in which certain types of discourse uphold or resist particular social relationships of power that reproduce dominant ideologies.

Other researchers have focused on ideologies in the agricultural context and revealed how they can mask the tensions and contradictions that are core to the dominant industrial, capitalist agricultural system. Houser et al. (2020) found that this ideology of industrialized agriculture was being maintained by farmers themselves through belief systems around fertilizer pollution – many farmers in their study re-produced ideological positions of market fundamentalism and techno-optimism, ideas that new technologies can and will offer solutions to environmental problems in agriculture, especially having to do with pollution issues surrounding fertilizer use. The authors see this process to be reproducing an ideology that ultimately limits a more widespread emergence of agroecological practices and transitions to address environmental problems in agriculture. Furthermore, Canfield (2022) discusses the ways in which the ideology of *innovation* has become pervasive in global food discourse; it emphasizes the role of science, research and technology, and has strategically been deployed in international contexts to suppress calls for a transition to agroecology. This paper follows methodologically from these prior studies but takes up a research agenda put forth by Klerkx et al. (2019) who called for scholars to interrogate the role of DA technologies in transitions towards sustainability. Similarly, by focusing on the Canadian context, this paper complements other scholarly conversations about future imaginings of DA in international discourse (Lajoie-O'Malley et al., 2020), and in Sub-Saharan Africa, specifically (Abdulai, 2022). The dataset for this research project was interrogated through the lens of the research question: *How is digital agriculture discussed in relation to environmental sustainability?* The research question was left intentionally broad and high-level to capture different conceptualizations of environmental sustainability that might emerge inductively from the dataset itself.

A systematic media analysis of the national and leading regional Canadian newspapers (such as the Globe and Mail, the National Post, the Calgary Herald and the Montreal Gazette) was conducted. Appendix A.1 shows the sources of all news articles included in this analysis. This was done through a Proquest database called Canadian Major Dailies, which provides current and historical content from more than 35 of Canada's major newspapers. Search terms included were: 'digital agriculture', 'digital farming', 'smart farming', 'precision farming', 'ag-tech', 'big data' and 'farming' or 'big data' and 'agriculture'. These terms were searched for in the context of their relationship to: 'sustainability', 'climate change'/'climate', 'environment', and/or 'regenerative agriculture'. Articles from 2016-2022 were examined, and 453 media articles were found. Ultimately, 256 were excluded due to irrelevance, and a further 19 were excluded because they did not address digitization in agriculture. Thus 178 articles were included in the analysis. Winnipeg Free Press had the most coverage of these topics during that time period. These articles were mostly written by the same few reporters, who were covering the agriculture technology beat in Manitoba. The time-frame was chosen because there has not been a major change in federal governance since Justin Trudeau's election in 2015. Furthermore, the Trudeau government has been more explicit about climate action than any government that has come before it (MacNeil & Paterson, 2016).

Media releases from Agriculture and Agri-Food Canada (AAFC) were also analyzed. AAFC is the federal department that is most heavily involved with providing funds to both farmers and ag-tech firms through various programs, like the Agricultural Clean Technology Program. These articles were accessed through the AAFC website and all articles that discussed the search terms above were included in the analysis. AAFC released 1031 media releases during the relevant time-frame. After screening, 955 articles were excluded due to irrelevance, and a further 38 were excluded as they did not address digitization in agriculture (see Appendix A.2). Other relevant government documents were gathered as well. These documents included, for example, the 2030 Emissions Reduction Plan, and the National Adaptation Strategy. Documents relating to the Fertilizer Emissions Reduction Target were also gathered. A list of these documents is provided in Appendix A.3. These documents were targeted if they had been mentioned in the media, or mentioned in other relevant documents. Thirty-eight government reports were analyzed in total. Importantly, provinces are also heavily involved in the governance of agriculture. Provincial policy documents were excluded as their analysis would have been beyond the scope of this particular research project. Research into the ideological positions of the Canadian provinces would be valuable as a *future* site of study – especially as agriculture is such a place-based and context-specific activity in Canada. For this project, choosing federal materials specifically is justified as, together, they effectively demonstrate the ways in which DA is framed on a country-wide scale.

Results: Discourses of Optimization

Discourse analyses have been conducted by others in this area of research, and my work builds upon theirs (Duncan et al., 2021; Fleming et al., 2018; Karlsson et al., 2018; McCaig et al., 2023). Analysis for this project was conducted using MaxQDA. A first round of inductive *open* coding was very helpful in understanding the myriad perspectives of the producers of the texts in the dataset (Cope, 2010). Strauss (1987) describes this process as a close scrutinization of the data:

“The aim is to produce concepts that seem to fit the data” (p. 28). A common theme that emerged throughout the dataset was that (implicitly or explicitly) DA is an enabler of environmental sustainability. A less common theme arose as well – that DA would *not* enable environmental sustainability (see Figure 4). Subsequently, a round of selective coding was done, which was more systematic in its approach. During this round, DA’s role as a solution to environmental problems was focused on more specifically. Many sub-themes arose during this round of coding, like “food waste” (DA is presented as a solution to high food waste), “fertilizer emissions” (DA is presented as a solution to high fertilizer emissions). An initial inventory of codes is shown in Appendix A.4. Through this round of coding, it became clear that a common theme among these codes was *optimization.* A third round of coding was conducted, which was again selective, in which the question posed of the data was “How are DA technologies presented as technologies that optimize?” And a follow-up question included “What variables are assumed to be optimized by DA?” Through this analytic process, ‘DA is a suite of optimizing technologies’ was a common discursive theme that was deployed in both media and government materials that were analyzed. It was evident that this discourse was *ideological* when the belief systems, norms, assumptions and values central to the discourse were taken into consideration (Van Dijk, 2013). Through the 254 documents analyzed, this overarching ideology of optimization communicates three things: One, that **environmental sustainability needs to be optimized** through the uses of emerging technologies like DA. Two, that **environmental sustainability will inevitably benefit** from the optimization of parameters that aren’t necessarily directly linked to environmental sustainability, like productivity. Three, that optimization will happen through the **quantification and datafication** of the agricultural environment – a process that necessitates the uptake of DA.

Section 1: Optimizing Stewardship of the Land

Optimization emerged as the dominant theme during the textual analysis. For example, in a 2022 announcement of an investment into the Agricultural Clean Technology Program (a funding program focused on three areas: green energy, precision agriculture and bioeconomy solutions), then Agriculture and Agri-Food (AAFC) Minister Marie-Claude Bibeau declared the following:

> *"Recent droughts and flooding across Canada are another stark reminder that Canadian farmers are on the front lines of climate change. This new wave of innovative green projects announced today under our Agricultural Clean Technology Program demonstrates our intention to help farmers optimize the stewardship of the land, while increasing their productivity and profitability."* (Agriculture and Agri-Food Canada, 2022a [AAFC media release])

Bibeau's statements that this program will enable farmer's to 'optimize stewardship of the land' is crucial in that it effectively demonstrates the ideological belief that there is an optimal way to achieve environmental sustainability in agriculture, and that 'clean technology', of which DA is a key element, will help facilitate it.

The federal Emissions Reduction Plan (ERP) (though it focuses much more directly on sectors like oil and gas or transportation) states:

> *"Across the country, farmers are already demonstrating innovation and ambition in the adoption of sustainable practices and technologies…Moving forward, more ambitious*

> *action is needed to further reduce emissions in the agriculture sector, move towards net-zero emissions by 2050, and maximize the potential of agriculture soils to sequester carbon."* (Environment and Climate Change Canada, 2022, p. 65 [government document])

Optimization means many things in different contexts, but in mathematical and computing contexts, it refers to the capacity "[to obtain] the best results under given circumstances" (Rao, 2009, p.1). The statements in the ERP might seem straightforward enough, but the key discourse being put forth here is that technologies, particularly DA (along with other types of innovation) will allow farmers to *minimize* their negative impact on the environment while *maximizing* environmental benefits of their practices (maximization and minimization being directly related to ideals of optimization).

More specific environmental indicators are also invoked. For example, a DA platform called Ukko Agro is said to "*help farmers optimize pesticide, water and fertilizer usage to operate more sustainably"* (Bouw, 2020). In a 2020 media release, a digital food processing system called Onipro was said to reduce food waste (another environmental indicator) by using optimized sorting techniques: "*A revolutionary internal and external optical sorting system will reduce food waste by optimizing the sorting of problematic onions"* (Agriculture and Agri-Food Canada, 2020a [AAFC media release]).

A specific environmental indicator is front-and-center when it comes to the optimization discourse: synthetic fertilizer. Often DA is presented as a mechanism to decrease inputs (like fertilizer), and so DA is used discursively as a proxy for environmental sustainability. For example, a representative of Farmer's Edge, a DA platform, was interviewed in a media article explaining how their technology could enable the optimization of fertilizer use:

> *"The platform collects and compiles data from a variety of sources – satellite imagery, soil testing, data analytics and computer modelling – to produce a "variable-rate prescription" for how farmers should apply fertilizer to their fields, among other things. That includes not only when to apply it, but also where to apply it, how much to use and even which fertilizer to use. The goal is to optimize the return on their fertilizer costs and minimize damage to the environment, said Dan Heaney, vice-president of research and development and agronomy for Farmers Edge."* (McNeill, 2016 [news article])

Furthermore, government documents highlight the principles of 4R Nutrient Stewardship (the approach encourages farmers to select the 'right type' of fertilizer, applying it at the 'right time' of year, at the 'right levels' in the 'right place'); DA technologies of different types could seemingly help with all 4 "Rs", yet it is particularly focused on for the "Right Rate" approach:

> *"Right rate matches the amount of fertilizer to crop needs. This entails only applying what can be taken up by the crop over the course of the growing season. This recommendation can include precision application technologies (including those that address in-field variability), and the use of soil tests to make nutrient management decisions accounting for existing soil nutrient levels."* (Agriculture and Agri-Food Canada, 2022b [government report])

The 4R approach is another clear example of the ideology of optimization – it asserts the idea that in every agricultural system there is a perfect way to apply these inputs – if only farmers were applying fertilizer perfectly, then the environment would not be damaged irreparably. The data presented in this section demonstrates that DA is often discursively employed as a mechanism to facilitate the optimization of environmental sustainability, which will, ostensibly, solve the deep environmental problems of the current food system.

Section 2: The Inevitability of Environmental Sustainability through Optimization

Frequently, the documents would imply that multiple factors, namely profitability, productivity and environmental sustainability, are being enhanced, improved and maximized simultaneously through the use of DA:

> *"By using big data, by using state of the art technology, by using 'the Internet of Things,' what you can do is develop a brand-new way of looking at climate-smart agriculture that is economically feasible and profitable, but also environmentally sound," Thompson said. "At the bottom line of it all is a safe, secure, high quality food system."* (Stephenson, 2017 [news article])

In another example, a farmer who was piloting a "digitally customized crop-plan package" developed by Nutrien, a multi-national fertilizer production company, explained: *"It's about being smarter in the way we plant," he says. "We see agronomy, economic and environmental performance completely aligned"* (Zary, 2020 [news article]).

Often, however, the element(s) or variables of the system that are actively being optimized through DA are synonymous with productivity or crop yields. The assumption that the optimization of these variables will in effect lead to improved environmental sustainability outcomes was common throughout the dataset. For example, in a 2016 report from AAFC, a segment on soil testing is illustrative:

> *Soil nutrient testing provides valuable information that producers can use to match crop nutrient requirements with nutrient levels in soil and nutrients applied in the form of manure and commercial fertilizers. This can help to maximize productivity and make the most efficient use of resources while reducing the risk of losses to the environment. The more frequently soil tests are conducted, the more opportunities a producer has to fine-tune nutrient applications in order to optimize crop growth.* (Agriculture and Agri-Food Canada, 2016 [government document])

Now, in 2023, many DA companies have popped up in this market, claiming to provide farmers with, for example, real-time plant tissue analysis, providing them with knowledge about plant growth, nutrient deficiencies, etc. without the farmer having to send soil samples to an off-farm lab, eg. Picketa Systems (Picketa Systems, 2023). In the AAFC excerpt above, environmental sustainability is assumed to be a predestined outcome of the process of optimization. Optimizing 'crop growth' is the predominant goal, while reduction of environmental risk is framed as a secondary outcome. In this text, it is indicated that DA (among other solutions) will uphold and sustain the environment, but *more importantly,* these technologies will sustain the status quo production system at the heart of the Canadian agricultural sector. A parallel example was illustrated in the 2022 Federal Budget: "*…farmers' resources, such as time and money will be optimized in a digitally enabled farming system.*" The document goes on to say that digital technologies can help reduce emissions (Department of Finance, 2022 [government document]).

The inevitability of DA and its supposed inherent sustainability factors is a key sub-theme of this discourse. A media article covering companies that were part of a Saskatchewan ag-tech accelerator program interviewed a farmer and asked him about his response to a DA robotics company:

> *"'What excites me the most is the potential efficiencies long term…the benefits to the environment and sustainability,' [the farmer] said, adding the technology's biggest appeal is its ability to turn reams of raw data into what he calls 'intelligent data' that informs better decisions. 'It's just a matter of time and it will look different, but I do believe we can get there…'"* (Rance, 2022 [news article])

This excerpt also speaks to the assumption that DA, through a form of digital calculative reasoning, analyzes a set of varied inputs and reduces them into an "actionable" output that is 'better' than prior decision-making strategies, perhaps ones based more on farmer intuition. Furthermore, by saying 'it's just a matter of time', the farmer invokes the inevitability of DA as an element of social (and environmental) progress. This perspective was commonplace as early as 2016 as well – a then CEO of a John Deere dealership organization, believed that predictive weather modelling, a common DA technology, would "*allow growers to make better business decisions that are going* *to lead to increased productivity in a more environmentally sustainable manner"* (Cash, 2016 [news article]). Through these examples, it is easy to see the ways that DA (and its optimization capabilities) is understood as a necessary tool to make all aspects of farming better, more improved, and closer to some optimal point. In the dataset, optimizing technologies are assumed as capable of facilitating net positive outcomes – in terms of time, profits, crop quality, and productivity indicators. This ideology of optimization is clear throughout the dataset: technological innovation is inevitable and necessary in agriculture; it represents progress. Environmental benefits stemming from the use of these optimizing technologies are a beneficial consequence and a reliable solution to agriculture's environmental problems.

Section 3: Achieving Optimization via Measurement

The process of optimization is enabled through the aggregation, measurement, standardization, and classification of data. According to McKelvey & Neves: "Optimization, firstly, presumes there is data, or should be data, to solve a new problem" (2021, p. 98). In the context of DA, the collection of boundless agricultural data is meant to enable more enhanced resource efficiency and management, as discussed in the previous section. In government documents like the Emissions Reductions Plan, there is a focus on the need to '*develop metrics'* (Environment and Climate Change Canada, 2022 [government document]), while the Guelph Statement, a government document related to the recently established Sustainable Canadian Agriculture Partnership highlights goals to '*enhance data collection' and 'performance measures*' (Agriculture and Agri-Food Canada, 2021 [government document]). The AAFC's 2022 Strategic Plan for Science, the '*application of data*' will contribute to multiple facets of sustainability (Agriculture and Agri-Food Canada, 2022c [government document]). The document stressed the need for agricultural data for the creation of a ‘sustainable and robust agriculture and agri-food system’. In an AAFC media release about an ag-tech start-up from British Columbia, it is highlighted that the measurement of nutrients in the soil is expected to change agricultural practices:

> *“During a visit to Terramera Inc. in Vancouver, who received $2 million through the ACT Research and Innovation Stream, Minister Bibeau witnessed first-hand the work underway to provide more consistent and precise measurement of soil carbon. Through the adoption of clean technologies, it is expected that this project will help to encourage farmers and ranchers to adopt regenerative management practices and to be incentivized for the carbon they sequester."* (Agriculture and Agri-Food Canada, 2022d [AAFC media release])

In this example, the measurement and reporting of soil carbon through a DA technology is delineated as a driver of “regenerative management practices”. In many ways, the discourse simplifies the concept of sustainability down into specific variables like, in this case, soil carbon. Another example of this discursive practice is evident from Farmer’s Edge; one media article from 2022 highlights the company’s plan to continue to develop technology that helps farmers track their sustainability achievements:

> *“[Wade Barnes, the CEO of Farmer’s Edge]… was one of the features speakers at a Tech Manitoba conference where he was extolling the value of the company’s ability to track the carbon footprint on the farm, something that will become increasingly important as global food companies try to meet their zero carbon targets in the coming years.”* (Cash, 2022 [news article])

Implied here is that DA is necessary, and that not only is the measurement of carbon needed in efforts to reduce emissions, but soil carbon measurement is also a sustainability practice in and of itself. So-called ‘carbon-farming’ has become a popular and much-discussed strategy to achieve GHG emissions reductions in agriculture (Sharma et al., 2021). Not only is it exemplary of strategies to *perform* environmental accountability, but it is also a mechanism through which the private sector is indicating that they do not need top-down interventions from the government in order to meet sustainability goals and avert the worst impacts of the climate crisis (Ghosh & Wolf, 2021).

Media discourse, however, can also highlight farmer skepticism with the idea that quantified agricultural systems are inherently better or more profitable than operations built on decisions informed by farmer intuition: “*The moneyball technique worked for baseball, but if I were to pit the human against the numbers, I wouldn't be able to pick a winner without considering the fact that my family's farm, which has been a successful operation since the late 1800s, has stayed alive and profitable because of the decisions people have made.”* (Dyck, 2017 [news article])

In this example, this farmer shows skepticism about the application of the ‘moneyball’ technique, referring to the 2003 Michael Lewis book *Moneyball: The Art of Winning an Unfair Game* about the use of statistical techniques like sabermetrics to optimize performance of under-funded American baseball teams (Lewis, 2003). Notably, this farmer doesn’t mention sustainability. Sustainability, however, is being deployed as a justification for endless data collection. The desire for datafication, quantification and assessment of sustainability measures on the farm is also driving platformization in this sector. Platformization, according to Poell et al., is understood as the "penetration of digital platforms' economic, infrastructural, and governmental extensions in different economic sectors and spheres of life" (2019, p. 5-6; see also: Srnicek, 2017). McKelvey & Neves (2021) also contend that the turn towards 'platforms-as-infrastructure' was a key point in the history of optimization, as they scale up and speed up the process (of optimization), enabling its proliferation into more facets of life. The following excerpt describes a digital platform being supported by the federal government:

> "*With this support, the CFA will create a single window for data on the sustainability of the Canadian agri-food supply chain. This will provide a forum where producers and processors can share information and connect with new networks interested in sustainability. This initiative will also serve as a hub to benchmark and track the sustainability of the Canadian agri-food industry compared to international standards.*" (Agriculture and Agri-Food Canada, 2020b [AAFC media release])

In such a way, the platform provides the infrastructure for data aggregation and the proliferation of quantifiable standards, as it works to demonstrate the achievement of certain sustainability 'benchmarks'. This is a key element of the process of optimization, as farmers can continually improve their practices in the attempt to achieve higher 'levels of sustainability'. This section has illustrated the ways that quantification of variables in the agricultural system is a key operation of the 'optimization of sustainability' in agriculture. Quantification simplifies the complex realities of agricultural ecosystems into sustainability indicators like soil carbon. The analysis also revealed that assumptions are made with regard to the capabilities of DA (and the data it generates) to enable more optimal decision making.

Discussion: The Impact of the Ideology of Optimization

This research has considered how DA is related to environmental sustainability in public and policy discourse in Canada. Through the research process, it became clear that DA is framed as pivotal to the *optimization* of agricultural practices. The sort of optimization processes that are positioned as being delivered by DA fit with the definition of optimization put forth by McKelvey & Neves (2021) as "a form of calculative decision-making embedded in legitimating institutions and media that seek to actualize optimal social and technical practices in real time" (p. 97). Though this 'calculative decision-making' is related to concepts of rationalization (Weber, 1968) scientific management (Taylor, 1911), efficiency, industrial productivism (Montenegro de Wit & Canfield, 2024) or computationalism (Golumbia, 2009), optimization as a unique concept arose from disciplines such as engineering, game theory and computing (Halpern & Mitchell, 2023). The concept, in its disciplines of origin, referred to an "internally referential and relative" measure of performance: "for *this* system, given *these* goals and *these* constraints, the optimal solution is X" (Halpern & Mitchell, 2023, p. 16 [emphasis in original]). This quest for optimality, however, has permeated other disciplines, like economics, since the 1950's and especially since the onset of neoliberal capitalism. This quest is premised on the foundational belief "that everything – every kind of relationship among humans, their technologies, and the environments in which they live – can and should be algorithmically managed" (Halpern & Mitchell, 2023, p. 17). While productivism and logics of efficiency have shaped the agricultural system for a century, optimization is a novel and acutely mathematical approach, made possible by data collection and analytics enabled by digital tools, infrastructures and platforms.

Moreover, throughout the analysis of the discourse about DA technologies and environmental sustainability, a distinct *ideology of optimization* became clear; this ideology asserts that through processes of optimization which centrally depend on the use of DA, an ideal agricultural system will emerge – one that is described as maximizing profitability, productivity, as well as environmental sustainability. A close look at the texts which further this ideology of optimization, however, reveals that this discourse sustains the status quo agricultural system, and with it, the normative assumptions built into what is the 'best' or 'optimal' way to grow food and organize the whole agri-food sector. Below, it is argued that this ideology of optimization works to keep intact an environmentally destructive food system, along with the inequitable power concentration among a handful of actors that are central to this current system. The ideology of optimization within political and public texts on DA achieves this maintenance of the hegemonic food system in several key ways: it keeps 'improvement' towards sustainability incremental, it draws attention away from more radical and transformative policies and pathways, and it rhetorically places solutions to environmental problems in the future. Below, the section demonstrates how political texts related to the fertilizer emissions reduction target in Canada provide an illustration of the deployment of the ideology of optimization via DA by positioning DA as the technical solution to political and environmental problems simultaneously. Finally, the last section explains how the concept of optimization could be useful to critical food studies scholars; and at the same time, how scholars considering the sociological impacts of optimization might benefit from a consideration of agriculture as a site of study.

The Impact of the Ideology of Optimization on the Food System

Optimization embodies incrementality in many contexts; for example, the hill-climbing technique is a mathematical procedure in which an algorithm iteratively improves its solution to a problem until some specific condition is maximized (Norman & Verganti, 2013). In the context of agriculture, the ideology of optimization promises that the food system can systematically and incrementally be improved (using digital technologies) to the point at which environmental impact would be negligible or even positive. Goldstein illustrates how the ideology of optimization operates among 'cleantech' entrepreneurs who subscribe to a kind of *planetary improvement imaginary*, wherein the technologies they innovate are able to achieve incremental gains, which are then framed as the initial steps towards "major environmental transformation…that will ultimately help save the planet" (2018, p. 2). He goes on to argue that these innovations result in technical solutions that do little to address environmental problems (p. 10). Fairbairn et al. (2022) have found these narratives to be common in the entrepreneurial world of DA. Likewise, Buttel discusses the ways that agricultural research and development prioritizes 'patching up' problems experienced by industrial farmers, while keeping intact the underlying conventional production system (2006, p. 218). Incremental change in agriculture is likely an inadequate solution for the uncertainties presented by catastrophic global climate change and biodiversity loss. Furthermore, the ideology of optimization and its techno-solutionist undertones re-direct attention away from other, more radical policies or changes that could be enacted in the Canadian food system, like for example, a shift towards a less export-oriented agricultural sector (Kanter et al., 2019).

The ideology of optimization also contributes to a problematic futuring of sustainability. As McKelvey & Neves contend: “optimization is never complete” (p. 107). If optimization is never complete - but optimization is a precondition for future sustainability – sustainability will never be achieved. The agricultural system may never be fully quantified and represented through data points, as such datafication becomes a never-ending process continuously in search of an ever more precise optimum (Halpern & Mitchell, 2023). The increasing unpredictability of a warming climate contributes to this phenomenon, as the mapping of agricultural variables will only become more complex in the future. Not only then does the ideology of optimization imply the continuous adoption of increasingly expensive and invasive DA technologies, but it always places the arrival at the optimum at some vague future point in time. Benessia & Funtowicz (2015) invoke the idea that we remain *waiting for sustainability* to be achieved in the future instead of making radical and necessary changes now (see also: Booth, 2023). They discuss the “need to shift from predicting and promising what to do (in the future) to a political resolution of how we want to live together (in the present)” (Benessia & Funtowicz, 2015, p. 329).

Furthermore, as the food system faces layered crises, quantification (a key operation of optimization) of current conditions creates a sense of techno-optimism and security, re-enforcing the notion that increased data collection will lead to solutions to the agricultural sector’s most catastrophic and urgent problems. Relevant here is Visser et al.’s (2021) work that complicates the narrative that the data generated by DA technologies is more precise than analogue data and farmer observation (due to lack of broadband coverage, weak GPS reception and sensor errors). Moreover, Krzywoszynska discusses the ‘farming by numbers’ approach: “a biopolitical regime in which farmers’ and advisors’ subjectivity is that of calculating managers situated in calculable environments" (2024, p. 1). Scholars who consider the social consequences of the preoccupation with quantification consider the harms it can cause. Porter (1995), for example, elucidates the critique that the practice of quantification and standardization reinforces technocratic governance and devalues alternate forms of knowledge. The turn towards digital quantification in agriculture can leave out, for example, Indigenous ways of knowing that are crucial in sustainable and equitable agricultural systems (Laforge et al., 2021). Furthermore, the digital platforms that enable this scale of quantification have sociological consequences in and of themselves (see: Goldstein & Nost [2022] for their exploration of environmental data infrastructures), and it remains to be seen how the process of platformization shifts the politics and practices of agriculture (see Reisman et al., 2024).

An Illustration of the Ideology of Optimization: The Canadian Fertilizer Emissions Reduction Target

Governments worldwide have begun recognizing the danger of high fertilizer-related emissions, and policies, mandates and targets have become a common mechanism for decreasing the negative environmental consequences of high fertilizer use. In the Netherlands, the *stikstofcrisis,* or nitrogen crisis, has "shaken Dutch politics to its foundations" (Tullis, 2023), as the government is planning for the forcible closure of high-polluting farms. Farmer-led protests have become common across Europe in response to environmental regulations of agriculture (Mathiesen, 2023). In Canada, far-right protesters have signalled their solidarity with Dutch farmer-protestors, waving Dutch flags during the Ottawa Freedom convoy protests of 2022 to signal their displeasure with government overreach in Canada and abroad (Montpetit, 2022). In fact, the Canadian government may be keeping the emissions target voluntary to avoid more significant unrest. What the ideology of optimization does in this case is allow the government to demonstrate and perform their desire to reduce fertilizer emissions, seemingly stay within planetary boundaries (Richardson et al., 2023) and give farmers the resources, approaches, and technologies to do so. However, since this ideological paradigm continues to uphold status quo industrial agricultural practices, it will be difficult to meet Canada’s 2030 fertilizer emissions reduction target without more drastic policy interventions (Vinco et al., 2023).

This section demonstrates how the fertilizer emissions reduction target deploys the ideology of optimization to keep current systems of fertilizer use in place, solidifying further the industrial and productivist paradigm of agriculture in Canada and the industry actors who are served by this paradigm. Many DA technologies have ostensibly been designed and are being promoted by industry and government in the name of, among other things, fertilizer use optimization. One tool that was mentioned numerous times in the dataset is a Canadian company called Farmer’s Edge (Farmers Edge, n.d.). DA platforms like Farmer’s Edge are critical in the application of the 4R approach to optimize fertilizer use. Again, this approach embodies the incrementality inherent in optimization techniques. Across the dataset analyzed above, the promise was present that evermore precise application will result in the achievement of the fertilizer target. It is important to reiterate here that scholars have found that these technological approaches have not yet proven themselves effective in the loss of synthetic fertilizer into surrounding environments (Blesh & Drinkwater, 2013). However, the ideology of optimization works to lock in the use of DA as the ultimate possibility for salvation. It presents the idea that the deeply rooted problem of high synthetic fertilizer pollution will be solved through expanded capabilities of datafication and quantification.

Furthermore, it places the arrival at the target in the future (2030, to be exact), further reinforcing current processes of optimization to reach it.

To achieve fertilizer targets by 2030, there are other possible policy interventions that could be considered. Vinco et al. in their research on farmers' reactions to the 2030 fertilizer target found that monetary incentives could drive fertilizer use reduction in impactful ways (2023). Furthermore, a significant amount of nitrogen fertilizer losses is associated with crop production for livestock feed (Chatzimpiros & Barles, 2013), and so campaigns to reduce meat consumption may have a consequential impact in terms of emissions reductions. Kanter et al. (2019) discuss more policy interventions that could directly and indirectly improve nitrogen management: these policies include everything from more restrictive effluent standards for wastewater management to reduce water pollution to packaging regulation to improve food preservation. Furthermore, organizations from the National Farmers Union to the United Nations argue that policies that support and fund small-scale agroecology and low-input production systems should be considered as well (Qualman & National Farmers Union, 2022; see also Frison & International Panel of Experts on Sustainable Food Systems, 2016). The NFU, in response to the fertilizer crisis, states:

> *"Rather than telling ourselves and each other that we have a plan, that we are moving toward sustainability, or that efficiency and technology and best-management practices will solve this, we must instead take up our roles as responsible, engaged democratic citizens and shoulder the very real worry that this is in no way solved."* (pg. 69)

Their response puts forth the idea that more transformational change might be possible *outside* the realm of techno-solutionism and optimization (Qualman & National Farmers Union, 2022).

At the Nexus of Optimization and Agriculture

Finally, this article contends that Critical Food Studies scholars and other social scientists interrogating DA can use *optimization* as a theoretical tool. The scholarly discussion of optimization in agriculture does have a precedent. Fitzgerald (2003) documents the transformation of American agriculture into the industrial project it is today in her book *Every Farm a Factory*, wherein she explains how the logic of efficiency drove the transformation that took place over the first part of the 20th century. She demonstrates the United States Department of Agriculture's role in quantifying agricultural life and production patterns in order to document US farmers' capabilities to be "'efficient', productive, predictable, marketable, and reliable" (Fitzgerald, 2003, p. 34). Blanchette, too, in his book *Porkopolis* (2020), discusses the drive for efficiency in animal agriculture. The industry prides itself on using every part of the pig, and that the *total* use of the animal is a masterclass in efficiency (Blanchette, 2020). DA is considered by many scholars (Bronson, 2022; Klerkx et al., 2019; Rose et al., 2023; Duncan et al., 2021; Miles, 2019; Montenegro de Wit & Canfield, 2024), yet its role as an *optimizer* of these environments could be more thoroughly explored.

McKelvey and Neves (2021) critique the ways "our bodies, tools, and institutions are now understood as endlessly optimizable" (p. 95). This article has presented ways in which our agricultural environments, too, are understood in this way by powerful federal institutions in Canada. Optimization studies, a still-emerging scholarship, should take agriculture seriously as a site of study. Critique of the concept of optimization in the context of digital technologies is still just emerging, with work done by Halpern & Mitchell (2023), and Halpern (2021). Powell (2021) explores how the ideal of optimization is built into the design of the 'smart city', and also, importantly, pervades the citizen efforts to resist these developments. McKelvey & Neves (2021) have introduced a critical perspective on the concept of optimization, and they consider the ways in which this logic is foundational to much of the technological infrastructure that undergirds society today. They engage with the ways that optimization has arranged society and has "deep historical roots in the management of bodies, capital and empire.' They invoke Rosenthal's work (2018) on the capitalist organization of slavery in the United States, where plantation owners determined the optimum amounts of productivity that could be gleaned from each slave and pushed them to meet that maximum. McKelvey & Neves (2021) consider the ways that optimization techniques are rooted in white supremacy and colonialism, ideologies that have driven the expansion of industrial agriculture in Canada (Rotz, 2017). In much the same way Critical Data Studies scholars should consider DA seriously (an argument that has been put forth by Bronson (2022) and others), those considering the societal impacts of optimization should consider the ways it's being operationalized in agricultural environments. McKelvey & Neves (2021) ask 'optimal for whom, when and where?' to trouble the idea that optimization results in perfect outcomes for everyone – these questions are particularly important in an agricultural system that has already been captured by powerful agribusinesses and ag-tech corporations (Bronson, 2022).

Conclusion

This paper has uncovered an *ideology of optimization* in political and public discourse on DA as it relates to environmentally sustainable agriculture. This ideology positions DA as the *best* method of agriculture in the face of the climate crisis, global food insecurity, and the biodiversity crisis. The ideology of optimization frames deeply rooted social and political problems as technical problems to be solved by the increased adoption of technologies that enable the quantification, datafication and standardization of agricultural environments. Food studies scholars could use the concept of optimization to study power in the food system as it intersects with environment and technology. At the same time, critical data studies scholars who think with the concept of optimization might do well to look beyond urban or online digital contexts to consider the ways that optimization might be used to study rural and agricultural environments. In the context of a catastrophically warming world, the ideology of optimization locks in an arguably narrow and problematic framing of our socio-environmental problems and limits our possible solutions. This ideology is doing a disservice to the imagination of radical new directions – ones that are capable of transformative change.

Chapter 2:
Seeding Capital:
Tracing the Limitations of Ag-Tech Actors' Imaginative Capacities to Facilitate Environmental Transformation

Author:

Sarah Marquis

Abstract

In 2022, the managing directors of Conexus Venture Capital & Emmertech, a Canadian venture capital firm, wrote in Canada's leading national newspaper, the Globe and Mail, that "Agriculture technology, or agtech for short, can (and should) be a leading catalyst in Canada's platform to combat climate change." They claim that increased investment funding in ag-tech will enable environmentally sustainable outcomes for the food system. This paper takes that claim seriously and interrogates how useful the investment funding model (particularly the venture capital model) is in this regard. In the process of doing this research, I conducted interviews with ag-tech actors in Canada who identify as technology designers in the ag-tech ecosystem, entrepreneurs, and, importantly, funders – those who control venture capital and direct it towards ag-tech start-ups. Using Milkoreit's (2017) theory of imagination as a guiding theoretical framework, the paper is built upon the premise that imagination is necessary in food system transformations towards sustainability and justice. The findings show that ag-tech actors' capacity to imagine sustainable food systems is significantly limited socially and cognitively, as they are unable to imagine food systems outside of relations of efficiency and environmental

control. They also tend to equate the adoption of digital technologies with the practice of sustainability. The findings suggest that ag-tech actors are incapable of the transformative imagination that is needed to facilitate sustainable agriculture in Canada. The political implications of these findings are discussed in the final sections of the paper.

Keywords: Venture capital, ag-tech, imagination, environmental sustainability, entrepreneurialism

Introduction

In 2022, Sean O'Connor and Kyle Scott, the managing directors of Conexus Venture Capital & Emmertech wrote in Canada's leading national newspaper, the Globe and Mail, that "agriculture technology, or agtech for short, can (and should) be a leading catalyst in Canada's platform to combat climate change." Indeed, agriculture contributes to climate change in myriad ways – through biodiversity loss, soil degradation, water pollution and greenhouse gas emissions (Clapp, 2020). It is also claimed that agricultural production needs to increase on a global scale to ensure that enough food is produced to feed a growing population (though emerging research calls for these claims to be revisited (Giller et al., 2021)). The solution to these converging crises in the food system, according to O'Connor and Scott, is the investment in and adoption of ag-tech. They explain why venture capital investment in ag-tech could unlock these companies' potential, and thus Canada could become a leader in the global ag-tech market. O'Connor and Scott claim this outcome would enable environmentally sustainable outcomes for the food system - I take that claim seriously in this paper and interrogate how useful the investment funding model (particularly the venture capital model) is in this regard.

Ag-tech includes technologies like digitized and automated machinery, remote surveillance technologies, precision agriculture technologies and farm management software. Proponents of these technologies have declared this proliferation of digital technologies a 'digital revolution' in agriculture (Barret & Rose, 2020). The Royal Bank of Canada, the largest bank in Canada by market capitalization, describes how Canada has lagged behind international peers – like Israel, Singapore, Japan and the Netherlands - in investment in ag-tech, and calls for the mobilization of capital into this space to "help cut potential 2050 emissions from Canada's agriculture sector by up to 40%" (Royal Bank of Canada, 2022). This is but one of many of ag-tech's 'promises' to optimize agricultural processes, allowing farmers to be more precise about their inputs, saving them money, and reducing the negative impact that agriculture has on the environment. However, there has been little evidence that large scale deployment of ag-tech has the capacity to reduce agriculture's significant negative impact on the environment (Clapp & Ruder, 2020). Furthermore, social scientists have begun to interrogate the role of ag-tech in the increasing corporatization of agriculture (Bronson & Sengers 2022; Fairbairn & Reisman, 2024; Stock & Gardezi, 2022). And Hackfort et al. (2024) and Bronson (2022) found that ag-tech has the potential to reproduce socio-ecological inequalities that contributed to the agri-ecological crisis in the first place.

Proponents of ag-tech (like O'Connor and Scott) imagine a future in which ag-tech has helped to solve overlapping environmental problems in agriculture. It is this process of imagination that I explore in this paper. We know from prior research that visions of the future have significant political consequences (Preininger, 2023; Sippel & Dolinga, 2022). We also know that ag-tech actors, who include technologists, venture capital funders and entrepreneurs, have the social and financial power to 'perform' these 'visions of desirable futures' (Jasanoff, 2015, p. 14). Cooiman (2022) demonstrates how VC investors, specifically, have the power to structure the digital economy and imprint their logics and imaginations onto start-ups seeking their attention and funding support. Therefore, it is highly important to understand the process of how these actors imagine the future, especially in terms of environmental sustainability in agriculture. I interrogate the statement made by O'Connor and Scott by questioning how investment business models, particularly the business model of venture capital, affect ag-tech actors' capacity to imagine environmentally sustainable agricultural futures. It is widely understood that sustainability transformations in agriculture are necessary – as it functions now, both the global agricultural system and the Canadian agricultural system are unsustainable (Buttell, 2006; Clapp, 2020; IPES, 2023). And it is *also* understood that sustainability transformations require imagination (Moore & Milkoreit, 2020). If ag-tech actors are framing ag-tech to be a catalyst, facilitating the sustainability transformation of the Canadian food system, it's important to understand how these actors' visions for the future are affected, limited, or dictated by the investment culture that they work within.

The structure of the paper is as follows: the literature review begins by contextualizing venture capital as a funding framework and how it is distinctly related to Silicon Valley. I then describe my theoretical framework in which I draw upon Milkoreit's (2017) theory of imagination. Following that, I discuss my methods which consist of interviews with 18 ag-tech actors (funders, technologists, founders and intermediaries/ consultants in the ag-tech industry in Canada). The results demonstrate that these actors' imaginations are socially limited by the conditions of entrepreneurialism in a volatile marketplace. Furthermore, they are cognitively limited by both the lack of understanding of sustainability, and the tendency to subjugate environmental sustainability to financial sustainability. Finally, actors were inclined to equate the adoption of digital technologies with the practice of sustainability. The discussion then dives deeper into the food system implications of these limited imaginations and considers future research agendas.

Context

Venture Capital in Canada and Beyond

Throughout the last few decades, the ag-tech sector, and many other technology sectors have been profoundly restructured due to contemporary funding frameworks such as venture capitalism (Cooiman, 2022). As Nicholas (2019) explains, the venture capital model is based on 'long-tail investing', in which many different start-ups are invested in, but only a few become extremely successful, making up for investments in start-ups that fail. VC firms raise funds from 'capital providers' – these could be governmental agencies, corporations, private individuals or other types of organizations. Subsequently, they invest in many different start-ups that they deem 'promising'. Typically, venture capitalists receive an annual management fee, along with capital gains from returns from investments (Cooiman, 2022), and they usually stay involved until there is an exit of some kind. The exit occurs when the start-up is either sold to another company, or the start-up begins being traded on the stock market – this is called an initial public offering (IPO). This point is referred to as a 'liquidation event' and at this point the formalized relationship between VC firm and start-up terminates. The VC model is not the only funding framework that start-ups use to acquire capital to grow their companies. They also raise capital from grants, friends and family, angel investors, and accelerators.

Though Nicholas (2019) claims that "the venture capital industry has been a powerful driver of innovation, helping to sustain economic development and competitiveness," critiques of the social impacts of VC abound. Edward Ongweso Jr. has called for the abolition of venture capital, explaining that the model has not resulted in innovative technologies with social utility (2023).

Silicon Valley, the geographic hub of global VC, has developed a sort of socio-cultural ethos that has attracted major criticisms. Gebru & Torres (2024), Benjamin (2019b), Dubal (2020), Sadowski (2020), Crawford (2021) and Harris (2023) have been vocal in their skepticism of technology start-ups' ability to solve the problems they are espousing to solve. Nevertheless, the high concentration of VC in Silicon Valley has produced companies like Uber, Facebook and Google, companies that have re-shaped the socio-technical landscape of the 21st century. However, as McElroy explores in their book *Silicon Valley Imperialism,* Silicon Valley both "manufactures and disseminates aspirations and entrepreneurial desires" (2024, pg. 16). It is worth exploring how these ideals of financialized capitalism are being taken up north of the border, in Canada. Notably, the Toronto-Waterloo region has emerged as an 'innovation corridor' that is in many ways modelled after Silicon Valley, with the goal of 'job creation' and 'economic value accumulation' (McKinsey & Company, 2016).

Venture capital funding models are becoming more prevalent in Canada, although investment has been affected by global events like COVID-19 (Croteau et al., 2021), and high interest rates. Tech industry actors are also wary of the newly announced capital gains tax (framed by the federal government as a 'wealth tax') that was announced in the 2024 Canadian federal budget (Department of Finance, Government of Canada, 2024). With specific regard to agriculture, however, companies had a record year in Canada in 2023 in terms of venture capital, with $273 million invested (Grieg, 2024). In summary, though ag-tech investments are growing in Canada, there is a fair amount of uncertainty in the marketplace. It should also be noted that the government of Canada has a broad range of VC funding mechanisms that invest in ag-tech: from Farm Credit Canada, which has a significant VC fund used to directly fund agricultural and food ventures to the Business Development Bank of Canada, whose venture capital arm manages over $6 billion, the largest venture capital institution in Canada (CVCA, 2024). The blurring of public and private capital is also apparent through the rise of other funding mechanisms like the Public-Private Partnership (Smyth et al., 2021). These programs and partnerships have been criticized for *crowding out* private capital, which is seemingly hindering the growth of an independent VC ecosystem in Canada (Cumming et al., 2017). Nevertheless, all levels of government in Canada signal the desire for a thriving VC economy (Department of Finance, Government of Canada, 2024).

Intersecting Digital Technologies and Environmental Sustainability

There has been a fair amount of emerging work done that demonstrates farmers' perspectives on ag-tech (Bronson, 2022; Carolan, 2020; Miles, 2019), however, less work has been done that demonstrates the perspectives of other ag-tech actors in Canada, like ag-tech funders, VCs, angel investors, entrepreneurs, technologists and consultants. Bronson & Sengers demonstrate that the turn towards the digital that is happening in agriculture concerns many more people than just the farmer, and that attention should be paid to other actors in this ecosystem (2022). Critical work has explored the political economy and science and technology studies dimensions of the investor-driven ag-tech industry in the United States, much of it coming out of the Agri-Food Technology Research (AFTeR) Project out of University of California, Santa Cruz (led by Julie Guthman). This work includes research from Biltekoff & Guthman (2022) which explores the ways that ag-tech actors imagine consumers and how that shapes their work. Fairbairn & Reisman (2024) show that though new start-ups are popping up at an unprecedented rate, industry incumbents absorb these new companies further entrenching patterns of corporate consolidation of power (see also Bronson, 2022; Bronson & Sengers, 2022; Cooiman, 2022; Steup, 2019). Alternatively, Sullivan (2023) explores the tensions between epistemologies held by ag-tech technologists and agro-ecologists and discusses the impacts of these two social groups coming together in the context of the 'neoliberalizing university' at the University of California, Santa Cruz. Fairbairn et al. contend that venture-capital backed ag-tech innovations are "couched in a discourse of revolutionary and systemic change," and that the ag-tech sector, specifically, "primarily offers incremental improvements on existing technologies, often developed or marketed in partnership with industry incumbents" (2022, p. 4).

Within this scholarship there remains room for research investigating the intersection between VC, ag-tech and environmental sustainability in particular (Klerkx & Villalobos, 2024). Work has been done that considers emergent digital technologies like AI and sustainability in other sectors. Crawford, for example, explores the energy inefficiencies of AI systems, exploring how the data centers required by AI "are among the world's largest consumers of electricity" (2021, pg. 43). Since grids in most countries (including Canada) are not fully renewable, the energy to power these behemoths comes from coal, gas, and nuclear sources. The phenomenon of the energy intensiveness of AI systems is beginning to get more and more attention, especially in the context of large language models like Chat GPT now being available to the public (International Energy Agency, 2024). A recent book by Becker (2023) considers cryptocurrency transactions as a significant source of CO2 emissions. The book goes on to provide a comprehensive treatment of the link between computing, sustainability and justice, but does not consider agriculture as a space where these elements are becoming increasingly relevant to one another. Nachtwey & Seidl claim that "relatively little scholarly attention has been paid to how those that design, develop and deploy the majority of digital technologies (claim to) see the world and their role in it" (2024, p. 92). In this paper, I seek redress for what we might see as an urban bias in the academic exploration of digital technologies and environmental sustainability, extending the existing literature on venture capital in ag-tech by focusing in on how actors in the Canadian ag-tech ecosystem 'see the world and their role in it'. In particular, I focus on the imaginative landscape for novel technology development and food system transformation.

Theoretical Framing: Ag-Tech, Venture Capital and the Imagination

Milkoreit's (2017) theory of imagination as 'interdependent cognitive and social processes' provides the fitting framework for the theoretical analysis of this research. Milkoreit explains that there are "two dimensions of imagination: (1) the cognitive-emotional processes that generate imagination in individual minds and (2) the socio-political processes that produce shared imaginations within a group or society, including imaginaries – bounded, and emotionally coherent sets of ideas about possible futures" (2017, p. 4). Moore & Milkoreit argue that the imagination has a *transformational* capacity, enabling "fundamental shifts in the way authority, power and resources are structured and flow in a particular social system" (2020, p. 4). This transformational capacity is particularly necessary in agriculture as this sector is a major driver of climate change while simultaneously becoming increasingly vulnerable to it (Melchior & Newig, 2021) Stoetzler & Yuval-Davis (2002) contend that the imagination is necessary in the transformation process, as it creates alternatives to already existing social and political structures, institutions, and relationships. Benjamin, in her 2024 book *Imagination: A Manifesto*, declares that imagination is a "field of struggle, not an ephemeral afterthought that we have the luxury to dismiss or romanticize" (pg. 8). She explores the relationship between imagination and power, explaining that the 'eugenic imagination', what she calls dominant techno-elitist imaginaries, marginalize people of colour and narrow our visions for the future.

There is a plurality of concepts in the literature on imaginations, imaginaries and their social and political importance. For example, *socio-technical imaginaries* are generally used to refer to "collectively held and performed visions of desirable futures," (Jasanoff, 2015, p. 14). Significant work has been done to demonstrate the socio-technical imaginaries that are dominant in the ag-tech industry and how they impact the food system. For example, Sippel & Dolinga (2022) argue that the dominant imaginaries in the ag-tech ecosystem work to legitimize the space for financialization – this process has various social consequences. Bronson (2022) explores how the imaginary of agricultural big data as raw, true and objective is held by both corporate actors and agri-food activists alike. All of these scholarly contributions are helpful and inform my work. However, Milkoreit (2017) differentiates between the imaginary and the imagination by framing imagination more as a process, both cognitive-emotional and socio-political, rather than a vision or projection. This process of imagination certainly creates imaginaries, and those imaginaries are significant, however the object of inquiry for this particular paper is the *process of imagination itself*, and how it is shaped by the context within which it happens. Relatedly, Benjamin calls the imaginary and imagination "conceptual kin, related but not identical" (2024, p. x). I ground this paper in Moore & Milkoreit's (2020) conceptualization of imagination vis-à-vis sustainability where they offer the idea of the failure of imagination in terms of our collective failures to deal with climate change, biodiversity loss and other environmental challenges. The linking of imagination and environmental sustainability, climate change and the human-environment relationship is explicit in this theoretical framing in ways that it is not within the socio-technical imaginary framing (Milkoreit, 2017).

Milkoreit's (2017) theory of imagination is also unique in that it conceptualizes the *capacity to imagine* as a key ingredient for transformation. The capacity to imagine is based on political structure, institutional processes, resources and power. Ag-tech actors like the ones I have interviewed for this research seemingly possess large capacities for imagination. They are encouraged to follow opportunities and develop or fund technologies that 'disrupt' current realities; therefore, one might think that they spend a good amount of time imagining what those disruptions would look like and how they would come about. VCs also hold a significant amount of 'ideational power' "understood as the ability to create new ideas and motivations in actors' minds" (Milkoreit, 2017, p. 10; Cooiman, 2022). I chose to interview these actors because they wield the structural power and financial resources to influence the innovation trajectories of emerging ag-tech. Furthermore, Milkoreit & Moore (2020), in their introduction to their special issue of Elementa introduce the articles which span from the imagination processes of policy-makers at the United Nations (Marzec, 2018) to the ways in which visual and performative arts-based imagination practices can support transformations to sustainability (Galafassi et al., 2018). Moore & Milkoreit explain that a "key actor type missing in this list is industry (beyond the film and book production/consumer industry) – a gap that we hope will be filled with future work" (2017, p. 7). This work addresses that gap as I consider the corporate imagination practices of ag-tech actors. My goal in this paper is to understand how ag-tech actors *imagine* sustainable food systems and theorize how these processes of imagination might be affected or even limited by the cultural and political economic contexts (specifically VC culture) in which they work.

Methods

In this paper, I empirically investigate the questions: **how do ag-tech actors imagine future environmentally sustainable food systems, and how are these imaginations impacted, limited, or prescribed by the conditions of the ag-tech industry itself (such as the influence of the venture capital business model)?** Instead of beginning a priori with a conception of sustainability, the work was inductive in the sense that actors were themselves asked about how they envisioned and defined agricultural sustainability as it relates to ag-tech. Recruitment of interview participants was conducted purposively through social media, specifically LinkedIn, with subsequent snowball sampling. I used a free trial for LinkedIn's premium platform to be able to cold message those who were a good fit for my research. I was intentionally open about the definitions of who I wanted to speak to - I wanted to speak to those working in the Canadian ag-tech ecosystem: funders, founders, technologists or intermediaries (consultants, or those working at industry non-profits/organizations). I wanted a portion of those I interviewed to be decision-makers or on decision-making teams for venture capital (or other types of capital) funds, and I wanted another portion of these interviewees to be founders and/or technologists affected by those decisions. It should also be noted that though there is a rise in social impact funding in Canada – an investment strategy that seeks to simultaneously generate financial returns and social or environmental impact – I did not specifically focus on impact investors in this paper. The social impact investing sector is less well developed in Canada than in other countries (Phillips & Johnson, 2021), and 'impact' is not very well defined throughout the sector anyway (Golka, 2024).

Ultimately, I conducted interviews with 18 Canadian ag-tech actors for this research. I started out by categorizing them into different groups: venture capitalist, angel investor, founder, technologist, but I found that many actors in this industry tend to hold multiple identities concurrently. A rough chart of the interviewees and their roles can be found in Appendix B.1. Furthermore, approximately half of the interviewees were also farmers or had significant experience growing up in a farming environment. These levels of domain knowledge were significant and shaped the interview conversations. Supplemental data was gathered from workshops with ag-tech actors in the United States, online webinars, start-up websites, corporate grey material (from organizations like the Canadian Venture Capital & Private Equity Association) and interviews with ag-tech actors working in Silicon Valley (since this research focuses specifically on Canada, I left those interviews out of the dataset for this article). This research is part of a larger PhD project which considers the broader relationship of ag-tech and environmental sustainability, therefore data collection from other parts of the project informed my interviews and interpretation of the data (see: Hackfort et al., 2024).

The interviews took place via Zoom or over the phone in the spring-summer of 2023. Interviews were conducted virtually due to constrained funding of the research project and inability to travel very far for interviews. Interviewees were mostly from Ontario and the Prairies, although a few were from BC and the Maritimes. I chose semi-structured interviews as a method because they are used in qualitative research to elicit information that answers specific questions, but also to give the researcher more intensive insight into the social processes and power relations that underlie their research (Longhurst, 2016). I had a preliminary conversation with an ag-tech actor based in Ontario to discuss the appropriateness of my questions. The interviews I conducted with respondents were informal and conversational, and I made space for flexibility, allowing the interviewees to expand on issues that they wished to talk about. The lists of interview questions used for these semi-structured interviews can be found in Appendix B.2, B.3 and B.4. The framing of my positionality was important for some of the interviews, as the interviewees held roles as conventional farmers. I did not want to be identified as an environmentalist or as hostile to their practices. I tended to identify myself as a PhD student in Environmental Sustainability interested in the relationship between ag-tech and environmental sustainability.

Topics of discussion ranged from ag-tech, to artificial intelligence in agriculture, to venture capital, to government involvement in agriculture. The interviews took place the summer after the initial release of Chat-GPT, and so the conversations tended to touch on the potential of generative AI to shift practices of agriculture. The interviews were recorded and then transcribed. Though Zoom automatically transcribes conversations, I took time to correct and check these transcripts as transcription is a crucial part of data analysis that allows the researcher space for thoughtful consideration of the data before the coding process begins (Kowal & O'Connel, 2014). Data was then coded using MaxQDA. The first round of coding was open: "the purpose of this stage is to 'open up' the data, fracturing them along the way if necessary, and breaking the data down so that conceptual implications can emerge in later steps" (Cope, 2010, p. 446). Special attention was paid to the cognitive and social contexts of participants' imaginations of environmental sustainability. A second round of axial coding was conducted, paying special attention to those themes – one particular theme was the pressure that ag-tech actors felt in the entrepreneurial context, and how this pressure affected them and the way they thought about sustainability. A final round of selective coding was completed which focused the ways that respondents equated digitization with sustainability.

Results

Throughout the interviews with ag-tech entrepreneurs and funders, actors explained to me how they make sense of environmental sustainability, how they consider it in relation to their work and if/how they see ag-tech shaping the future of environmental sustainability in agriculture. The results show that their meanings and imaginations of what environmental sustainability could be in the future are narrow and limited. It became clear that their imaginations of environmentally sustainable agricultural systems were shaped by the *social* context of entrepreneurship, competitiveness and a volatile and unpredictable financial marketplace. Furthermore, only certain ways of imagining the future food system (ie. a highly digitized food system) seemed mentally coherent with their current identities and world views, demonstrating limitations on their *cognitive* imaginative capacities. Overall, these actors tend to conceptually equate digital agriculture and sustainable agriculture; to them, the digital and the sustainable are one and the same.

Social Imagination in a Volatile Marketplace: "There's a lot of pressure for sure...."

Throughout the interviews, it became clear that the *conditions of the marketplace* were a major limiting factor that affected the ways these actors could imagine the future. Risk, for example, is built into the business model of VC, and many of the actors working within this ecosystem position themselves so as to avoid high-risk investments; simultaneously, however, they *take* high risks in order to acquire high financial rewards (Nicholas, 2019). VCs deploy 'risk capital', capital that is exposed to possible loss, every time they decide to invest in start-up firms. One VC described the business model succinctly:

> *…venture capital is a highly specialized type of financing. And, rightly or wrongly, there's so many failures in the companies that we invest in that we need to have some level of probability that the ones that are going to succeed, are going to provide financial returns that are large enough to overcome all the failures of other folks in the portfolio. (IV.16, Pos. 12)*

VCs, however, are also responding to the ways that the tech marketplace has shifted in North America in the past decade. One VC working at a relatively new fund - that has just recently turned towards ag-tech after being a general technology fund for a period of time - speaks to the volatility of the investment marketplace post-COVID:

> *I also think that the kind of 8 to 10 year run where it was just a bull tech market, you just toss money at a technology company, and it's gonna toss you twice as much back like, that's gone. And I think that was really a result of just a really strong economic environment. And then COVID hit…and people are thinking about fundamental businesses, like I think gone are the days where Uber is worth billions, but they lose money at the end of every quarter. (IV.12, Pos. 16)*

Here, the temporal dimension of investing in this space was emphasized. She refers back to an era of investment in which risk of commercial failure was not taken as seriously because there was capital flowing into the marketplace with ease. Now, however, there is much more attention paid to ‘business fundamentals’, like the ability to scale and monetize the start-ups that she and her team invest in. One VC, who also identified as an entrepreneur, explained:

> *I've never experienced tougher times in my forty year career than right now…“No, I don't think people understand the repercussions of Silicon Valley Bank going under and how much unease [has been] created in the marketplace. So, we're flying straight into those headwinds right now, every day, every day.”* (IV.9, Pos. 46).

He goes on to explain that times are difficult because of the increase in interest rates and the reluctance of VC firms or other types of funders to take the risk to commit capital to new, small start-ups. He refers to the Silicon Valley Bank, a bank based in the San Francisco Bay Area which was the preferred banking institution for many venture-backed start-ups. However, after the increase of interest rates in 2021-2023, a bank run on deposits led to its collapse in March 2023 (Cruickshank, 2023). This was telling as it demonstrated the ways in which the failure of a bank headquartered in California was causing founders in Canada to be uncertain of the stability of their industry, especially as it caused certain types of financing to decline in the period after the collapse.

The concern with the volatility of the marketplace was common throughout the interviews with those who identified as VCs or entrepreneurs. They sometimes identified their positions in the marketplace as precarious, dependent on larger forces that were mostly outside of their control. This is significant in the context of imagination, as imagination can be conditioned and determined by social norms and positioning (Moore & Milkoreit, 2020; Stoetzler & Yuval-Davis, 2002). The social norms of ag-tech entrepreneurialism in a volatile and uncertain marketplace shaped their capacities to engage in imaginations of sustainable futures and the technologies that could play a role in these futures. One interviewee had co-founded a VC firm and had subsequently come across a mushroom harvesting robotics firm that had been deemed by his firm to be too high-risk for VC investment. The interviewee had believed in the company, however, and so he became an angel investor and took on the role of CEO (notably, this exemplifies the myriad ways in which ag-tech actors move fluidly through different roles within the ag-tech ecosystem; many VCs I spoke with were concurrently playing the role of entrepreneur, and so they would slip in and out of that identity throughout the interviews). He explained the pressure he felt to facilitate the success of the company:

> *I'm an investor myself personally in this. So there's a lot of pressure for sure…I mean, we're working extremely hard, we have to be very focused on getting product to market and demonstrating working on farm because…it's quite a tight industry, it's a, you know, $15 billion global industry, but it's very tight in terms of the players involved in the marketplace. So, if it doesn't work, word's going to spread quickly.* (IV.5, Pos. 23)

He frames this decision as a risky one: the technology that he has invested in *must* become financially successful or he will risk failure – the loss of his investment and the loss in social standing among his peers. And since the company was specializing in the production and commercialization of a robotic mushroom harvester, it *was* risky. Hardware is notoriously more difficult to commercialize than software, as the margins are smaller. Notably, his vision of environmental sustainability had to be compatible with his vision of success in other respects. He discussed sustainability in this context; he talked about how the mushroom harvesting technology would reduce human labour thus reducing food waste: "*…because of the lack of labor, there's a huge wastage of mushrooms of about $200 million a year. Just because people aren't there to pick the mushrooms on time. They grow 4% an hour and the retailers want them at exactly 55 millimeters*" (IV.5, Pos. 59). His imagination of a sustainable mushroom harvesting farm was a vision where inefficiencies were reduced as much as possible. He did not question whether the larger elements of the system needed to be altered to create a more sustainable system. He did not, for example, question whether or not the 55-millimeter standard imposed by retailers might be changed, as that change might also reduce food waste. Milkoreit (2017) describes how the social environment, like shared behaviours and institutions, can shape imagination. She also theorizes about how "social processes can generate, change, or supress imaginations." These findings tend to demonstrate that the volatile social context of entrepreneurialism - seeking VC (on the part of entrepreneurs) or providing VC (on the part of VCs) - constrains the imaginations of what ag-tech is ultimately for.

Ag-Tech Actors and their Cognitive Imagination: "I don't really think I understand sustainability..."

Another important finding was that sustainability, or the need or desire to lead sustainability transformations in agriculture was not core to the identity or thought processes of the ag-tech actors I interviewed. This affected their cognitive ability to imagine technologies beyond those that would garner them financial success, which, as discussed in the previous section, is a primary motivating factor for their engagement in imagination. Furthermore, throughout the interviews, there was uncertainty around the definition of 'sustainable agriculture' and how it would be achieved. This finding is not surprising as the term 'sustainability' is a buzzword, contested in many ways, and considered a boundary object – interpreted in different ways in different contexts (Constance, 2018; Scoones, 2007). For example, one start-up founder found it difficult to parse through the different meanings of sustainability. His start-up was developing robotics technologies for large (3000+ acre), broadacre farms in the Prairies, and his definition of sustainability was shaped by the experience of innovating specifically for this farmer/user base. I asked him what he envisioned as an environmentally sustainable agricultural system in 10 or 20 years:

> *"That's a difficult question for me, because I don't really think I understand sustainability. Because there are so many different aspects to sustainability. Do I look at sustainability for the farmer? Because honestly, I haven't really focused much on sustainability myself. My main focus has been trying to solve a critical problem at the moment. One aspect of sustainability is to make sure the farmer can continue farming,*

> *continue their operation year to year without worrying about their labor. Just mak[ing] sure their operation is sustainable."* (IV.19)

Though I was asking about environmental sustainability, throughout his thought process his conceptualization became business-oriented, explaining that the technologies innovated by his start-up help the farm continue operating into the future. Milkoreit explains how the process of cognitive imagination is driven by a tendency to "maximize coherence between different aspects of a situation, e.g. different goals, data and evidence, motivations and past experience" (2017, p. 4). IV.19 was uncertain about the term 'sustainability' and its implications, and so other meanings were mapped onto the concept to achieve mental coherence. What was being sustained in his imagination was, in effect, industrialized agriculture, not necessarily the well-being of the natural ecosystem. He seemed to be lacking the cognitive tools to discuss *environmental* sustainability, and he went on to say: *"…for [small] startups like us, I know that they want to be careful, but most of the time, they don't really understand sustainability"* (IV.19). This would suggest that these cognitive limitations are common among many ag-tech entrepreneurs.

As Milkoreit (2017) considers the ways that imagination of the future can spark motivation in the present, I was also considering how desire for change in the current system can also be a motivating factor for imagination. However, in the case of my interviewees, the desire for radical system transformation rarely arose. I spoke with one VC who also had significant experience as an entrepreneur. He was also an active farmer, so he had high domain knowledge of the agriculture and ag-tech sectors. We were discussing climate change and the potential need to adapt to new weather patterns:

> *So, you know, I'm a scientist, and even if we change everything, I suspect the weather's gonna keep evolving and adapting, and as long as we get rain here [and] we don't dry out the Great Lakes, you know, we're probably pretty blessed to be living in Ontario, even if it does get a couple degrees warmer. You know, as long as we have water, and we don't get crazy desert or something. So, I think we're in pretty good shape in Canada. (IV.6, Pos. 72)*

Though there is high scientific consensus that climate change will negatively impact agriculture and make food production more uncertain and difficult (Clapp, 2020), this actor was not motivated by the potential (and current) consequences of climate change to imagine a significantly altered agricultural system. These actors' imagined identities as producers, as entrepreneurs, as venture capitalists, as 'builders' (as one VC put it), were mentally incoherent with *transformative* environmental sustainability. The VC/farmer above also seems to be engaged in cognitive distancing "an active process that represents climate change as something that is distant from the individual…" (Milkoreit, 2015, p. 123; see also: Norgaard, 2011), as he is insinuating that climate change won't be a significant challenge in the future. Notably, this is also related to his geographical context. He was not necessarily worried about climate change in Southern Ontario because of the ubiquity of freshwater. This would definitely differ from the mentality of ag-tech actors and/or farmers in Silicon Valley, located in California, an epicenter of drought and worsening water issues.

Another VC was explaining the thought process of deciding whether or not to invest in a start-up. Many investors operate according to an investment thesis, a set of criteria designed to help with this decision-making process. I asked him about the role environmental sustainability played in that decision-making process.

> *"So if there's a technology available, but you know, the byproduct of using that, or one of the ripple effects is environmental contamination or water issues....well, that that's going to be a non-starter for us…So, I think with any technology, we have to fundamentally see either status quo impact or less impact… (IV.13, Pos. 25)*

While this VC explained that measurable harm to the environment was a disqualifier for investment, he went on to explain that 'status quo impact' met the investment criteria. This, too, demonstrates that these actors are not necessarily motivated to imagine transformation because the current agricultural industry is working as designed and as intended. Another consultant I spoke with brought up a company that she really enjoyed working with, a Canadian start-up from Winnipeg that was in the process of acquiring a different start-up, demonstrating fast and successful growth. I asked her if this company had wanted to impact environmental sustainability in any kind of way with their product, and she responded: "*They didn't mean to, but they will, which is nice. I mean, that's an extra bonus*" (IV.2). She went on to explain how the use of this technology would lead to incremental environmental benefit, a tendency that Goldstein critiques at length in his book, *Planetary Improvement: Cleantech Entrepreneurship and the Contradictions of Green Capitalism*. Her framing also conveys a lack of intentionality in terms of transformation – maintenance of the current system is the goal, change is not.

The Contours of Imagination: The Digital as Sustainable?

When I asked interviewees what a future vision of sustainable agriculture looked like to them, almost without fail, they tended towards conceptualizing environmental sustainability as higher technological adoption. What they were doing, discursively, was equating the adoption of digital technologies with the practice of sustainability. For example, the following actor worked as an intermediary, coordinating an ag-tech accelerator program and connecting founders with VCs; he answered my question about a future vision for environmental sustainability in the following way:

> *"In my perspective, you'd see high adoption of technology, but it's all technology that's creating more profitable, more efficient farms and food systems. So, I think if all of those things align, then it's really good."* (IV.17a)

The following respondent, a successful start-up founder who had received funding from other VCs I had spoken with through the course of the research, leaned into techno-solutionism in his response when I asked him about how he saw the environmentally sustainable farm of the future. He envisioned digital technologies as solving environmental problems, in some ways he understood the digital *as* sustainable:

> *It's a big question…so everything will be basically digital and monitored constantly and basically, taking the worry out of a lot of it…You don't even need to think about what fertilizer to put on, it's getting automatically applied by a variable rate sprayer that goes*

> *out into the field only when it's optimal [to] do so and looks at the weather. When will it be absorbed? What's the best type of fertilizer to apply? So, taking a lot of the kind of intuition and just [making] it more data-driven. And automating a lot of it. So just connecting all the solutions will be a big one. That's maybe six, seven years away. (IV.7)*

This same founder went on to discuss how he did not even really need to explain to his investors why the technology he was producing was good for the environment as "*they already understand that precision agriculture is inherently better for the environment"* (IV.7). In his conceptualization, sustainable meant *optimized* and sustainable meant *controlled*, a system in which all risks and variables are accounted for. Different types of relationships (relationships of care, for example) with and within the agricultural system were rarely considered by respondents when they were asked to consider future sustainable systems. Another ag-tech consultant put it like this:

> *…I think what it boils down to is digital tools that allow for the interaction with the physical world to be controlled, in different ways that were not otherwise, were not previously possible, right. And that, again, I think, really can be about efficiency. (IV.11)*

Another VC simply said, when asked to forecast the future: "*Yeah, I think would just be more productive. I think we're gonna have more robots and automation…and that's all data-driven"* (IV.6). These findings are in line with the techno-solutionist perspectives Guthman (2024) writes about (see also Guthman & Butler, 2023).

In summary, these findings demonstrate both the social environments that ag-tech actors work within, as well as their cognitive patterns and tendencies, limit ag-tech actors' imaginations. The volatile social environment of entrepreneurialism influences their imaginations of environmental sustainability, which are subjugated to the need to both succeed among their peers and profit financially. Additionally, they are limited cognitively in that their conceptualizations of environmental sustainability need to mentally cohere with their current notions of agriculture, which is generally understood by these respondents as a project to control and optimize the natural environment. The ultimate result is that in the imaginations of these actors the *digital* becomes revolutionary and transformative in and of itself, eclipsing and replacing concepts of environmental sustainability.

Discussion

Despite the declaration by Sean O'Connor and Kyle Scott, the VC investors I mentioned at the beginning of this paper, that VC-funded ag-tech, could be a "leading catalyst…to combat climate change," the findings suggest that ag-tech actors are incapable of the transformative imagination that is needed to facilitate sustainable agriculture in Canada. What ag-tech actors are ultimately able to achieve are what Goldstein calls 'non-disruptive disruptions': technologies that are pitched as transformative and radical, but ultimately offer only incremental changes to existing systems and markets (Goldstein, 2018; Fairbairn et al., 2022). Though entrepreneurialism is usually associated with creativity and innovation (Haiven, 2014; Vehar, 2013), there is little evidence that ag-tech actors have the capacities for imagination on a transformative level. These actors are highly impacted by the social conditions of a volatile marketplace and they are unable to understand the dimensions of environmental sustainability or see themselves as truly responsible for shifting the food system towards environmental sustainability. Finally, these actors tend to equate the adoption of digital technologies with the practice of sustainability, which solves these problems of mental incoherence. This discussion summarizes the political implications of these findings. Furthermore, I discuss how this research contributes to the critical social sciences focused on ag-tech, environmental sustainability and food systems. I argue that these actors they cannot be relied upon to deliver the sustainable agriculture outcomes they allude to in press releases and marketing materials. Finally, I consider possible future research trajectories and explore why imagination (as a social and cognitive process) should be taken more seriously in sustainability scholarship.

While imagination can be a resource necessary for sustainability transformations, imagination can also be both limited and limiting. In the words of Stoetzler & Yuval-Davis, “The imagination is the source of freedom, change and emancipation as much as a source of the borders and boundaries that emancipation wants to challenge” (2002, p. 324). For example, carceral imaginations (Benjamin, 2019a) and eugenicist imaginations (Benjamin, 2024) have envisioned extraordinarily violent ways of governing human life. In the context of Canadian agriculture, productivist and colonial imaginations have been foundational to the industry (Rotz, 2017). These imaginations have shaped the material practices of agriculture, influencing the growth of the size of Canadian farms, the intensification of monoculture, and the liberalization of trade in agricultural goods (Wiebe, 2022; Fitzgerald, 2003). And as other scholars have found, ag-tech designers tend to design tools specifically for industrialized, monocultured environments (Bronson, 2018; Miles, 2019). This finding is supported by my data, exemplified by the engineer/entrepreneur who was specifically marketing to 3000+ acre farms in the Prairies. There is no doubt the other ag-tech actors I interviewed are also deeply influenced by the productivist imagination that shapes so much of agricultural production in Canada. This is yet another layer of complexity that hinders ag-tech actors' capacity to imagine more radical possibilities for just and sustainable food system futures.

The findings also suggests that the venture capital funding model impacts the imaginations of ag-tech actors in myriad ways. This business model essentially requires scalable and monetizable technologies that can be marketed towards as many users (usually farmers) as possible (see also: Cooiman, 2022). If ag-tech entrepreneurs are chasing VC funding, as many of them are, their imaginative capacities for new ag-tech are highly limited by the needs of VC. These entrepreneurs, though privileged in many ways, seem to be navigating feelings of dependency: on the market, on investors, and on other structures and institutions beyond their control. Lauren Berlant, in their influential work *Cruel Optimism*, argues that this feeling of precarity is a near ubiquitous feeling in contemporary capitalism. 'Cruel optimism,' "a relation [that]….exists when something you desire is actually an obstacle to your flourishing," Berlant theorizes, is an affective response to this feeling of precarity (2011). Successful ag-tech innovations, ones that attract investment from VCs and successfully exit through IPO or acquisition are promises that precarity and dependency will one day be made worth it. It exemplifies Berlant's cruel optimism in that actors remain attached to the entrepreneurial ethos despite the risk of failure being so high (Berlant, 2011; Slutskaya et al., 2018, see also: Carolan, 2023b). This cruel optimism acts as an imaginative blinder, it "locks individuals into harmful fantasies because abandoning them would require, even more painfully, becoming someone new" (Winant, 2021). While cruel optimism is exemplified by ag-tech entrepreneurs' pursuit of attention and investment from VCs, we can also see it manifesting on a larger societal scale in techno-solutionism as a response to catastrophic climate change. In the context of these layered social conditions, actors cannot internalize alternative visions for sustainable food system futures, as it would be too painful to question the salvific properties of the ag tech innovations they play such an important role in creating.

Ultimately, VC appears limited in its capacity to facilitate the fundamental change required to combat environmental crises as it is built on an ethos of speed, scale and growth. Given the evidence presented in this research, I would suggest that policy-makers consider the potential incompatibility of VC (and related funding models) with sustainability transformations in agriculture. This is particularly relevant in Canada where many public dollars go towards venture capital funds to be invested in agriculture through institutions like Farm Credit Canada Ventures and the Business Development Bank (CVCA, 2024). In fact, the Canadian federal budget released in 2024 explicitly supports Farm Credit Canada in their investment in ag-tech, citing these technologies' capacities to 'mitigate climate change' (Department of Finance, Government of Canada, 2024). Canadian agricultural policy-makers should perhaps instead support the creation of publicly-funded programs to reduce carbon emissions in agriculture (NFU, 2023).

This research contributes in multiple ways to the burgeoning critical social sciences considering digitization in agriculture (Klerkx et al., 2019) Much work has been done to describe the socio-technical imaginaries of ag-tech actors (Bronson, 2022; Sippel & Dolinga, 2022; Biltekoff & Guthman, 2022; Bomford, 2023; Gugganig et al., 2023; Guthman & Butler, 2023). While much of this work is coming from the Science and Technology Studies Food and Agriculture Network (STSFAN) (international) and AFTeR (California, US) research networks, there is significant scholarship in this area being done in the Global South as well (Abdulai, 2022; Canfield & Ntambirweki, 2024; Fairbairn & Kish, 2022). However, by using Milkoreit & Moore's (2020) framework of imagination, I believe I have offered something new to the field. By considering imagination as a process, as a transformative capacity that can be either limited or built out, we can begin to gauge possible future research agendas to produce novel understandings about how to enhance imaginative capacity with regards to ag-tech and its role in sustainability transformations. Furthermore, much of the work on imagination and climate change focuses heavily on the creative arts as a mechanism to imagine alternative futures to climate collapse (Milkoreit & Moore, 2020; Yusoff & Gabrys, 2011). *Corporate imagination* and its impact on innovation trajectories have yet to be researched substantively in the context of imaginative capacities for transformation (Milkoreit & Moore, 2020). Though there is substantial work considering the socio-technical imaginaries of corporate actors and their socio-political impact (Sadowski & Bendor, 2019), Moore & Milkoreit's (2020) work is especially useful because it explicitly considers the relationship between imagination and sustainability transformations. I call for future research to consider the ways in which corporate actors' (especially those claiming to be innovating 'clean' technologies) capacities for imagination are shaped by their social and cognitive contexts.

This research also contributes to this active scholarly conversation on the social and political dimensions of ag-tech by considering how VC in this sector is operating in the Canadian context. Many (though not all) of my interviewees had deep domain knowledge, having been farmers in the past or involved with the agricultural community in some other way. Their knowledge that comes with agricultural experience has informed their conceptualizations of sustainability and how to or not to engage with it. One investor specifically spoke about the reluctance of farmers in his community to engage with environmental sustainability, and to change their practices accordingly (IV.10). These perspectives have no doubt impacted his investing principles. These characteristics set these actors apart from stereotypical American VCs with little domain knowledge of agriculture (Guthman, 2024). Their imaginations are further limited by productivist ideologies that are ubiquitous in the conventional agriculture sector in Canada, which would also limit their abilities to imagine sustainability transformations in agriculture. Another thing that sets Canada apart is the involvement of the state: BDC, the Business Development Bank of Canada, is a crown corporation and is the largest actor in venture capital in Canada (CVCA, 2024). Furthermore, many Canadian ag-tech start-ups (including many included in my research) have been funded by the Sustainable Development Technology Fund, a publicly funded federal agency that used to distribute investment funds to ‘clean-tech’ start-ups in Canada. The Sustainable Development Technology Fund was recently found to have awarded funding to ineligible projects (Office of the Auditor General of Canada, 2024). In 2023, a whistleblower testified that there were numerous breaches to the institution’s conflict of interest policy (Leblanc, 2023). This raises questions about the efficacy and the very real possibilities for corruption in using public funds in a venture capital model to achieve sustainability transformations.

Further research agendas could consider if there are ways to build imaginative capacities of ag-tech actors or if the limitations of the VC environment (and capitalism at large) are too constraining for transformative thinking. There are many scholars who have questioned the capacity of the Canadian food system firmly rooted in capitalism and colonialism to transition to sustainability (Holt-Giménez, 2017; Blay-Palmer, 2016), and this work adds to that conversation as it maps the limited capacity of actors deeply involved in venture capitalism to facilitate sustainability transformations. Alternatively, there is significant scholarly attention being paid to alternative food initiatives, food sovereignty and agroecology in Canada (Laforge et al., 2021; Desmarais, 2022). I would suggest that more research be done to consider the ways that the imaginative capacities of radical organizations like the National Farmers Union and Union Paysanne could be enhanced and made stronger. Furthermore, Milkoreit (2017) considers the ways that structural power and imagination are related, and the way that inequalities in structural power constrain collective imagination. It is important to place my research within the context of a food system that has deep structural inequalities and unevenly distributed capacity for transformative imagination. Though much work is being done that considers the structural inequalities in agriculture and food and how these inequalities can be made smaller, imagination should be a key piece of building power for alternative food movements.

Conclusion

In this paper, I have explored the ways that ag-tech actors are limited in their capacity to imagine alternatives in the food system. I attribute these limitations to the conditions of the VC marketplace, which requires actors to imagine technological solutions in very specific ways. They also are not motivated to see themselves as responsible for moving the needle in any meaningful way in terms of sustainable agriculture. Lastly, I found that they tended to equate 'digital' with 'sustainable', making coherent these two concepts in their imagination of what is possible. Speculation about the future of food, possible new worlds and new relations required for transformations to sustainability has been reduced to a speculation of value, financial risk, and profit. This paper opens with a quotation from several key ag-tech investors in Canada. They claim that more capital flowing into VC funds and thus ag-tech start-ups will help to address climate change among other environmental problems faced by the agricultural sector in Canada. This research illustrates the problems with the premise of those statements. As many scholars have demonstrated, sustainability, especially in the food system, requires transformative imagination. It seems to be that the conditions created by VC (and the larger neo-liberal capitalist system within which VC plays a key role) create barriers to the transformative imaginations needed in this moment of food system and climate crisis. Yusoff & Gabrys contend that the imagination is a "site of interplay between material and perceptual worlds, where concepts cohere, forces pull and attract, and things, discourses, subjects, and objects are framed, contested and brought into being" (2011, p. 517). What I have learned from this research with ag-tech actors is that this 'site of interplay' is quite limited and specific. The lack of ability to imagine sustainable agriculture as *anything but digital* is not particularly surprising. Technological solutionism abounds in VC and entrepreneurial spaces, and other scholars have critiqued the role of capitalism in constraining imagination. However, this narrowed imagination could result in various social, political, economic and material consequences for agriculture and entire food systems. The question of what exactly is being sustained through digitization should remain a priority.

Chapter 3:
Harvesting value:
Corporate strategies of data assetization in agriculture and their socio-ecological implications

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Abstract

The global food system is characterized by market concentration and oligopoly. In our article, we focus on the most powerful input supply and machinery companies and analyze how these firms create value, both economic and otherwise, from big data. In digital capitalism, data is valorized across sectors; personal data is aggregated into large-scale datasets, a practice that feeds economic concentration and monopolization. Big data also has become central to the business model for agricultural companies; it is a claim made by the companies themselves. Yet, little is known about their specific strategies to do so. We aim to fill this gap, asking how is agricultural data transformed into value by the most powerful agribusinesses and ag-tech firms? Through the lens of assetization, we examine corporate strategies for transforming agricultural data into value. We draw on literature from food studies, specifically political economic analyses of the historical practices of agricultural corporations, as well as literature from critical data studies that investigates data as an asset. For our analysis, we rely on a variety of gray literature and public-facing documents: financial documents, sustainability and shareholder reports, terms of use, license agreements, and news articles. Our results contribute to the critical data studies literature on agricultural big data by identifying three main strategies of assetization: securing relationships and dependence, price-setting and data sharing, and product development and targeted marketing. The strategies have socio-ecological implications; our results indicate the reproduction of asymmetrical power relations in the agri-food system favoring corporations and the continuation of long-standing dynamics of inequalities.

Keywords: big data, platforms, corporate strategies, digital agriculture, data assetization, critical data studies, critical food studies

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Introduction

The global food system is characterized by intense market concentration and oligopoly; a small handful of firms exerts control over research agendas, policies, and the everyday lives of farmers and consumers (Clapp, 2021; Howard, 2021). Based on their market share, we focus on powerful seed and chemical (e.g. Syngenta, Bayer/Monsanto) and machinery (e.g. John Deere) firms and analyze how these firms create value, both economic and otherwise, from big data. Many of these companies appear to be shifting their business practices to focus on data as a key asset and driver of profit. In our era of digital capitalism, data is valorized across sectors; personal data is "harvested" and aggregated into large-scale datasets (Zuboff, 2019). The use of personal data for corporate gain has sparked lively public debates and academic interest not least because corporate data practices appear to feed economic concentration and monopolization. Google, Facebook, and Amazon's data-related business models and data valorization methods are well-known (Birch et al., 2021; Mayer-Schönberger & Cukier, 2013; Prainsack, 2019; Sadowski, 2019). Yet the data practices of agricultural corporations have yet to be empirically examined.

That big data has become central to the business model for agricultural companies is irrefutable (Bronson, 2022); it is a claim made by the companies themselves. Syngenta's CEO, for example, has said: "Before, we sold pesticides, seeds, and fertilizer. Now we're a [digital] farm services company" (ETC Group, 2022, p. 21). John Deere expects that by the end of the decade, 10% of the firm's annual revenue will come from digital platform user fees (Tita et al., 2022). Bayer/Monsanto has been building up one of the largest agricultural databases in the world, and in 2014, Monsanto acquired the weather analytics company The Climate Corporation; this is likely why Bayer acquired Monsanto in 2018, in the largest acquisition in global history.

In recent years, Wysel et al. (2021) has put forward a descriptive analysis of corporate practices surrounding agricultural data, and Klingenberg et al. (2022) has conducted a case study on an agricultural value chain to evaluate the impacts of digitalization on valorization. One key finding of this work is that platforms operated by non-agricultural actors like IBM or Alphabet Inc. are well positioned to create value from farm data. Trail (2018) outlines ways this might be done, highlighting the data ownership issues that sensor-based tractors and "precision" equipment could raise and the resulting need for corporate uses of farm data to be regulated.

Aside from this work, almost no work has empirically detailed the specific strategies these firms will use to profit from farm data. The absence of empirical examination of the exact uses of data collected from farms is a problem; scholarship has indicated unique features of the agricultural sector in the era of big data that deserve unique critical data studies (see Bronson & Sengers, 2022; Stone, 2022a). Scholars note that while anyone can use social media platforms in exchange for their data being collected, farmers, even after contributing their data without remuneration, must pay to access the data-driven advice offered by agricultural firms. And though big tech companies like Facebook are now considered some of the most influential in the world, the oligopoly of agricultural corporations has influenced the fate of national agricultural policies, farmers, and consumers longer than any other power (Birch et al., 2021; Bronson & Sengers, 2022). Thus, the question of what exactly input supply companies do with big datasets configured from farm-level data is worth examining empirically.

In this article, we ask: how is agricultural data transformed into value by the most powerful agribusinesses and ag-tech firms? To answer this question, we draw on critical food studies and science and technology studies literature on historical corporate practices related to profit generation. We analyze strategies of big data assetization as they intersect with iniquitous political and economic relations in the food system, which have been described at length. We rely on analyses of the historical practices of agricultural corporations, as well as critical data studies research that investigates data as an asset outside of the agricultural sector. We also draw on gray literature and public-facing documents related to input supply corporations: financial documents, sustainability and shareholder reports, terms of use, license agreements, and news articles. Based on empirical examination, we identify three valorization strategies for agricultural big data: Companies, we find 1) use data to lock farmers into relationships with particular firms; 2) use big data analytics for price-setting and hedging, and they also profit from the sharing of big datasets; and 3) use big data internally, to drive product development, and for targeted marketing. In the end, we argue that big agricultural data gives agricultural firms unique and incommensurate advantages over farmers and consumers and that harvesting agricultural data is thus likely to enable increased corporate concentration in agriculture.

Ultimately, our article fills a gap in empirical analyses of agricultural firms' big data practices and thereby adds specificity to scholarly and public conversations on the societal implications of agricultural big data practices. A longstanding feature of the agri-food system is economic asymmetries related to new technologies, which agribusiness companies have for centuries used to dominate markets and create relationships of dependence with farmers (Clapp, 2022). Today, control over data flows may reproduce existing power relations and socio-ecological inequalities in agriculture at the expense of data and environmental justice (Hackfort, 2021). In the service of a more just and sustainable food system and a broader conversation in critical data studies, we believe that a systematic overview of the strategies involving big agricultural data is of the utmost importance.

Conceptual Framework and Methodology

The guiding framework for our analysis is the concept of assetization, which was developed to account for the political economy of "technoscientific capitalism" (Birch & Muniesa, 2020), where income streams are increasingly generated from financial resources and properties, which are intangible. An asset is "something that can be owned or controlled, traded, and capitalized as a revenue stream, often involving the valuation of discounted future earnings in the present" (Birch & Muniesa 2020, p. 2). This framework is appropriate to our research because we focus on processes of extracting value from agricultural data in both the present and the future. Birch & Muniesa (2020) comprehensively argue for assetization's suitability as a conceptual apparatus for studying the generation of value—both economic and otherwise—from data in relation to larger political economic relations. Our argument builds upon theirs, providing novel empirical work that demonstrates processes of assetization in the context of agricultural big data.

Assetization denotes the collection of data with potential future value; data assets are not necessarily bought and sold directly on commodity markets in the same way wheat is, for example. Rather, data is collected and deemed valuable and worthy of investing in based on its assumed ability to generate future income, revenue, and returns. To derive these revenues, firms must commit sustained attention and effort to data assetization—a process that Birch et al.

(2021) delineate in the context of Big Tech firms' assetization of personal data for the purposes of locking in future users, targeted advertising, and other monetization strategies.

Assetization also draws attention to the fact that data assets are legal constructs underpinned by ownership and control rights (for instance, intellectual property rights), regulatory and market devices, and practices such as exclusivity agreements (Birch 2020, p. 3). Access to, control of, and use of data are granted and can be limited through legal rights, agreements, and licenses. These modes of ownership and control further differentiate the process of assetization from the process of commodification.

Lastly, data assets are not easily reproducible or substitutable without access to the original data source; they thus encourage monopoly and oligopoly by putting new entrants to the marketplace at a disadvantage while incumbent firms grow increasingly powerful. In this context, as they mediate relationships between users and corporations, digital platforms provide infrastructure that is crucial for the assetization of data. Assetization processes have been analyzed in the contexts of personal data (Birch et al., 2021) and the gig economy (Doorn & Badger, 2020; Gregory & Sadowski, 2021). As we know from empirical studies of Amazon and Google, in the age of "surveillance capitalism" (Zuboff, 2019), such companies use online behavior data points to predict users' preferences and future behavior; these predictions are then sold to third-party clients—for instance, advertisers. Irrefutably, both personal data and the platforms that collect it have become profitable assets. Zuboff (2019) has thus defined personal data as a "new asset class."

Amid this breadth of high-quality scholarship, however, there is a lack of attention paid to the assetization of agricultural data. Unique to the context of agriculture, machinery companies' sale of "precision" equipment (like the new John Deere tractors) provides a route by which they can collect data from farms. What is meaningful—and unique to agriculture—is that some of the most powerful, longstanding, oligopolistic corporations have recently been turning to these strategies of agricultural data assetization (Bronson & Sengers, 2022). The concept of assetization, however, has not yet been used to direct empirical examinations of these practices, so it is here that we focus our attention.

To guide our analysis and our selection of firms for study, we draw on critical food studies. As scholars in that field have illustrated, agribusinesses have become increasingly consolidated, and several mergers and acquisitions during the last two decades have resulted in enormous market concentration in the two most important agricultural sectors. Four companies now dominate the chemical and seed markets: Bayer/Monsanto, Corteva/DuPont and Dow, ChemChina/Syngenta, and BASF (Clapp, 2021; ETC Group, 2022). In the agrochemical sector alone, these four companies combined make up 65.8% of global sales, and for commercial seeds, ChemChina, Bayer, Limagrain, and Corteva account for 53.2% (Howard, 2020). Like the farm inputs and agricultural commodity industries, through mergers and acquisitions, the machinery manufacturing market has also become characterized by concentration in the last century. Today, just a few firms possess a major share of the market (Clapp, 2022).

Of these, the largest agricultural machinery companies are included in our analysis—John Deere, CNH Industrial, AGCO, and Claas. By now, every large agrochemical or agricultural machinery company has acquired or developed at least one big data-based farm management platform.

To investigate how these firms transform agricultural data into value, we analyzed a variety of documents, including license agreements, which empirically speak to ownership and control rights as key elements allowing for assetization. We also analyzed background material on the companies and their products and services on websites, including their sustainability reports, financial reports, and earnings calls. Financial reporting is only mandatory for public companies, so in some cases, especially start-up ag-tech companies, the financial documentation we were able to find and analyze was limited. Additionally, we reviewed academic work and gray literature, including NGO reports and newspapers, which detail historical economic practices among agricultural companies, such as discriminatory pricing and price-setting. We also analyzed the digital agricultural platforms and services themselves in depth wherever possible. While our analysis primarily concentrated on the largest agribusinesses, where relevant, we also included insights on other corporate actors, their subsidiaries, and start-ups they have acquired (see Table 1 for an overview of the analyzed material).

The background material was analyzed using software-based qualitative content analysis (MAXQDA). Coding was an iterative process of deductive and inductive analysis, beginning with a list of key terms (such as “ownership,”, “access,” and “third parties”) compiled largely from other studies of big data (critical data studies) and of data assetization outside of the agricultural context.

Table 1: Analyzed Background Material

Company and subsidiaries	Location of headquarters	Tools and applications	Documents analyzed
Bayer Notable Subsidiaries: The Climate Corporation (United States)	Germany	CFV, Bayer AgPowered Services	Annual Reports, Terms of Service, Privacy Statements, Sustainability Reports
Syngenta Notable Subsidiaries: Strider (Brazil), Cropio (Switzerland)	Switzerland	AgriEdge Excelsior, FarmShots, Strider (suite of applications), Cropwise Operations	User Agreements, Privacy Policies, Terms of Service, Financial Reports, Sustainability Report
Corteva Agriscience DowDuPont Notable Subsidiaries: Granular Inc. (United States)	United States	Encirca, AcreValue, MapShots AgStudio, Granular Insights	Privacy Policy, Terms of Use, Sustainability Report
BASF	United States	xarvio Digital Farming Solutions	Terms of Use, Privacy Policy, Sustainability Reports
Yara	Norway	Atfarm, DPP Digital Production Platform	Privacy Policy, Digital Farming Terms
John Deere Notable Subsidiaries: Blue River Technologies (United States)	United States	John Deere Operations Center, See & Spray	End User License Agreement, Data Services Statement, Privacy Notice, Privacy Statement, Terms and Conditions, Annual Financial Reports, Earnings Call Transcripts, Sustainability Reports
CNH Notable Subsidiaries: Raven Industries (United States), Augmenta (Greece)	United Kingdom	AgXtend; Raven Slingshot, Augmenta Mantis, Augmental LiveVRA	Annual Financial Reports, Privacy Policy, Terms of Service, End User License Agreement
AGCO	United States	Fuse Smart Farming, AgCommand	Privacy Statement, Machine Data Statement
Claas	Germany	365FarmNet	License Agreement, Terms of Use, Data Protection and Data Security Agreement

Microsoft	United States	MS Azure Data Manager for Agriculture (formerly FarmBeats), Trimble Agriculture	Microsoft Products and Services Data Protection Addendum, Privacy Policy
IBM Notable Subsidiaries: The Weather Company (United States)	United States	Watson Decision Tool for Agriculture	Annual Financial Reports, Data Security and Privacy Principles
Farmer's Edge	Canada	Farm Command, eScout	Annual Financial Reports, End User License Agreements, Privacy Policies
Semios	Canada	AgWorld	Terms and Conditions, Privacy Policy
One Soil	Canada	OneSoil Scouting	Terms of Use, Privacy Policy

Table 1: Analyzed Background Material

Corporate Strategies of Data Assetization in Agriculture

Through analysis, we have arrived at two overarching arguments. The first is that any attempt to systematically examine what agribusinesses do with agricultural data is impaired by legal mechanisms that obfuscate data practices, datasets, and algorithms: copyright, intellectual property law, trade secrecy law, and arbitration agreements all allow for proprietary technologies and a high degree of vagueness and opacity. This is a finding in and of itself; such obfuscation prevents critical analysis and the kind of oversight that the equitable governance of technology requires. Our second, broader argument is that data itself is very likely an asset for agricultural firms, which now uniformly include big data-based services in their portfolios. These companies are dominant in not just their traditional areas of technology, but also in offering digital farm tools, particularly big data-driven decision support platforms. Apart from a few start-ups that have gained a foothold in the market, the development and provision of digital technologies and services is dominated by the same handful of companies that supply agricultural seeds, biotechnology, pesticides, fertilizers (including Syngenta, Bayer, BASF, and the Norwegian multinational Yara), and farm equipment (e.g. John Deere and Claas). Syngenta has heavily invested in takeovers of farm management platforms, and it claims to be the only company with access to the leading farm management platforms in the world's top four agricultural markets: the United States, Brazil, China, and Eastern Europe (Syngenta, 2023). Bayer is also an important player here given its ownership of Climate FieldView (CFV), which in 2018 had more than 100,000 registered clients who together farmed on more than 120 million acres in the United States, Canada, and Brazil (Bayer's CFV, 2022b). We can confidently assert that for agribusinesses, data now generates revenue alongside input and machine supply. In line with our assetization framework, companies appear to be investing in data collection and analytics for their own sake, quite apart from using datasets to generate the advice provided by the farm decision support tools licensed to farmers.

Below, we outline three strategies that firms use (or are likely to use) to generate value from agricultural data (these are detailed, with examples, in Table 2). We also refer back to the conceptual underpinnings of our article to discuss how these strategies can be understood as assetization.

Table 2: Assetization strategies of agricultural big data (references are given in the text)

Assetization Strategies	**Practices**	**Examples**
Securing relationships and dependencies	Data lock-ins	Users of the **Semios** product Precision Agriculture As A Service™ can request access to their farm data, but it is provided in a format of the company's choosing. Semios also reserves the right to reject data requests, potentially making it difficult for users to switch their data from one platform to another.

		The lack of interoperability of data formats nudges farmers to remain customers of certain companies.
	Soft lock-ins (free trials, rebate programs, incentives, loyalty programs)	Farmers usually pay a subscription fee of $100/year to use CFV Plus. However, the subscription fee is waived if users sign up for the BayerPLUS Rewards program. This rewards program incentivizes users to purchase seed and agrochemical products from **Bayer** rather than other input firms.
	Carbon farming programs	**BASF** is launching a Global Carbon Farming Program that allows farmers to generate carbon credits that can then be sold to generate a secondary revenue stream. These emerging carbon labels are designed to be closely tied to corporate digital monitoring tools and enable flows of data directly into specific company platforms.
	Outcome-based pricing programs	With **Bayer**'s "outcome-based" pricing program, the firm sells seeds and agrochemicals based on a performance guarantee (e.g. a specific crop yield or level of weed reduction). In cases of shortfall, Bayer makes up the difference to the farmer. In cases of excess, they split the difference. While this is sold as a tool to help farmers "manage risk" more effectively, it also helps the company build stronger business relationships with its users.
Price-setting and data sharing	Data sharing	**John Deere**'s Data Services & Subscriptions Statement declares that, after the firm anonymizes and aggregates data that is generated from its machines and/or uploaded to its platform, John Deere Operations Centre, it may share data in aggregate, statistical form, non-personal information with partners, affiliates, or advisors. It is not specified who these partners, affiliates, or advisors are.
	Price-setting	In 2019, CFV (**Bayer**) stated in its Privacy Policy that it would not use personal data or aggregated farm data for the purposes of seed pricing. In 2023, that language is missing from the Privacy Policy, which may indicate that Bayer is engaging in seed pricing.
	Insurance (alliances with insurance firms, selling insurance products)	In 2021, **Farmers Edge** launched a new subsidiary company called DigiAg Risk Management Inc. The company will provide Canadian users with "innovative parametric insurance products," and its predictive abilities will enable insurers to reduce costs and invest more shrewdly—and profitably.

Product development and targeted marketing	Predictive maintenance	With **John Deere**'s Service ADVISOR Remote tool, the firm "can remotely analyze Diagnostic Trouble Codes (DTCs) in near real time to isolate issues with the machines." Farmers may pay at least twice—for the service contract and with the data they provide via the machinery. Yet such data clearly helps the company further improve its products, gain a competitive advantage in the market, and further strengthen relationships with its clients.
	Targeted marketing of seeds/inputs/equipment	The Climate Corporation's Seed Advisor tool recommends **Bayer** products to users. Using farm data, its predictive tools recommend the most high-performing seeds from Bayer's proprietary seed genetics library—the largest in the industry. This may limit farmers' options and result in a lack of diversity in the crops grown.
	General marketing uses	**Raven Industries**' End User License Agreement for its Raven Slingshot product explains that advertisements and promotions will be displayed to the user. The agreement goes on to state that these advertisements can be targeted to the user's farm data that has been uploaded to the platform.
	Improvement of digital products and services	**AGCO**'s legal agreement states that farm data will be used in on-going product development and improvement initiatives This is standard across the industry.

Table 2: Assetization strategies of agricultural big data (references are given in the text)

Securing Relationships and Dependencies

Agribusinesses have historically used a variety of mechanisms to corner the market on agricultural inputs and machinery, establish exclusive relationships with farmers, and create different kinds of lock-ins and forms of dependency from within their economic–technical ecosystems. They have created relationships of control with farmers by cultivating their dependence on proprietary technologies—Monsanto, Syngenta, and DuPont—for instance, offer discounts and rebates to those who purchase their seeds and use their complementary herbicides and pesticides (Clapp, 2021; Curry, 2023). Agribusiness companies have also used intellectual property rights (in the form of, e.g. patents and trademarks) to tie farmers to seed systems by making it nearly impossible to switch systems without legal repercussions (Bronson, 2015; Shiva, 1991). Firms use leasing and financing arrangements to create lock-ins and dependencies among farmers. For example, John Deere, one of the world's largest manufacturers of farm equipment, offers financing for its equipment, making it easier for farmers to purchase its products. However, this also creates dependencies, as farmers are more likely to purchase future equipment from John Deere to maintain their financing relationship (John Deere US, 2023b).

One well-known example of dependency in the digital era is the "digital lock" on John Deere tractors, which contain sensors for collecting data and sending it to cloud-based infrastructures. Legally, this makes them digital rather than mechanical tools, like mobile phones. As such, their use is controlled by a license agreement under which they are leased, not owned, and may only be repaired by certified mechanics; farmers may not fix tractors themselves, nor may they access the data the machines generate (Solon, 2017). After years of contestation by activist organizations (see IFIXIT.org), John Deere has reached an agreement with the American Farm Bureau Federation to partially remove the lock. Yet, as observers argue, this partial concession might erode efforts to bring about broader, legally binding measures that would be stricter in terms of data sovereignty (PIRG, 2023). The current legal architecture, consisting of lax regulation and the absence of binding protections for farmers, is the basis for data assetization, as it leaves room for unknown future uses of data, which might benefit corporations by prioritizing their access to datasets over that of farmers.

Legal tools and mechanisms like the copyright restrictions built into terms of use or license agreements are not the only techniques that appear to further relationships of control and dependence between farmers and firms. Our analysis shows that a lack of interoperability among the most powerful companies' data-based decision support platforms also works in this way, erecting barriers that prevent farmers from changing to (or even trying out) different systems. Companies such as John Deere have direct access to the data collected by the sensors and GPS systems installed in its machines, and increasingly, they also control that data. Farmers who buy new tractors cannot opt out of collection—crop data is automatically transmitted (along with other data) to a cloud-based infrastructure and used by the company's decision support platform and its proprietary algorithm. The company combines data from the level of individual farms with broader environmental datasets on weather and soil to generate recommendations that are sold to farmers. But notably, once a farmer's data has been uploaded, even if they were granted access to it, the lack of interoperability between companies' platforms would make it difficult for them to retrieve it and switch to another system (e.g. Semios, 2022). The lack of interoperability and compatibility among software and hardware systems from different providers is a persistent problem for farmers in many countries (e.g. Atik & Martens, 2021; Higgins et al., 2017; Stock & Gardezi, 2022), one that constrains their ability to choose systems based on their changing needs and locks them into a relationship with a single tool and company— and that company's inputs. This lack of interoperability drives the monopolization of data, which is a key feature of assetization.

Alongside data lock-ins, companies use "soft" lock-in strategies to create path dependencies for farmers. While some companies can access data directly through the devices built into their machinery, others dangle carrots in front of farmers in exchange for access—free “starter packages,” for instance, or BASF’s xarvio Field Manager app, which is offered for free for a limited time (BASF xarvio, n.d.). Through such incentives, as with biotechnology seed-chemical packages (Shiva, 1991), farmers are likely to become path-dependent on the technological systems of the companies whose machinery and software they initially purchase. Such strategies are not entirely new: elaborate incentive structures have long encouraged farmers to rely on bundled corporate products. As Kelloway (2022) reports, through its BayerPLUS Rewards program, Bayer offers farms a per-acre cash rebate for buying its products; buying chemicals in addition to seeds can result in savings of several dollars per acre. Such rewards can save commercial farms operating on more than a thousand acres thousands of dollars (BASF, 2023a). Similar rebate programs are offered in relation to data. With its Grow Smart Rewards program, BASF offers cash-back rewards to farmers using its digital agricultural platform in combination with the company’s pesticides (Arc, 2018). Bayer’s CFV, a big data analytics platform, is offered “free” to users who also sign up to BayerPLUS Rewards (Bayer’s CFV, 2022a; Stock & Gardezi, 2022). In 2018, CropLife reported that to widely distribute the platform and achieve a high level of market reach, Bayer/Monsanto used rebate incentives to encourage not just farmers but also retailers to adopt digital technologies. Because the latter are offered rebates should they reach certain sales targets, it likely makes financial sense for them to occasionally sell products like CFV at a loss (Kelloway, 2022).

We see evidence of a creeping adoption of data technologies tied to rebate programs, mirroring Bayer’s offer of tiered CFV subscriptions beyond the free basic platform, which incentivizes incremental adoption by providing additional features and services at marginal cost (Bayer CFV, 2023). BASF's xarvio Scouting app is also free, and xarvio Field Manager is free for two fields (BASF xarvio, 2023). Companies in the agricultural industry commonly offer basic, entry level tools for free to attract farmers and introduce them to products; these new clients then prove a return on investment. However, after they have already bought into, adopted to, and fully incorporated particular technological systems, early adopters may be required to pay for assistance or to access more advanced features and services.

Furthermore, corporations such as Syngenta, Corteva, BASF, Bayer, John Deere (partnering with Cargill), and Microsoft (partnering with Trimble) are increasing the marketability of their platforms by integrating current trends around climate-smart agriculture, sometimes using terms like "regenerative farming," which are meant to signify sustainable food production (BASF, 2023b). For example, Bayer offers an "annual cash payout" for participation in "carbon farming" programs that use the CFV platform to "verify" farmers' practices (Bayer AG, 2022). Many firms have launched programs to pay farmers for adopting carbon sequestering techniques. These emerging carbon credits are designed to be closely tied to corporate digital monitoring and control tools, thus enabling the flow of data directly into specific company platforms. Proprietary business models can mean that farmers enrolling in a company's carbon program simultaneously sign up to use its products, as in the case of Nutrien (FarmRaise, 2022). Moreover, data collected from farmers provides valuable information on their production practices and yields. To verify carbon credits, detailed information about planting is collected not just from technology at the level of farms and their equipment, but also from satellites. Some private carbon programs expand their user base by requiring farmers to directly upload information to proprietary digital platforms. These companies may take ownership of farmer-generated carbon credits, paying farmers either a portion of their sale price or at a fixed rate. Once they have sequestered carbon, farmers may need to sign long-term contracts to store it, giving payment platforms exclusive access to their data. This consolidates farm data among the largest agribusinesses, which already control large datasets and use them to create and optimize their algorithmic decision support products (Kelloway, 2021); it also creates barriers for newcomers, who may not have access to large datasets. On the surface, the implementation of systems of verification appears to be a win–win situation, a shift toward "green practices" that pays back farmers and ensures companies future revenue from data. However, such practices further strengthen ties between farmers and specific companies, eventually working as lock-ins for farmers and further strengthening oligopoly within agriculture. It is these processes of collecting large amounts of data via established, monopolistic platforms that make data assetization possible in the first place, as the basis upon which new business models can then be developed.

Another example of a soft lock-in is Bayer's "outcome-based" pricing program, in which the firm sells seeds and agrichemicals based on performance guarantees like specific crop yields or levels of weed reduction (Gullickson, 2019). Similarly, farmers who pay for BASF's xarvio Field Manager buy not a product but guaranteed, predetermined yields linked to specific, data-based recommendations (Burwood-Taylor, 2021). While this strategy presents a kind of risk-sharing between farmers and corporations, if the product outperforms the firm's predictions, the farmer loses a portion of the additional profits—potentially around half, according to one report (Gullickson, 2019). While this is sold as a tool to help farmers "manage risk" more effectively, it also helps BASF build stronger business relationships with farmers and allows for better pricing control. There is mounting concern over this corporate strategy: "Farmers and antitrust scholars worry that goliaths such as Bayer will use this data-driven pricing program to further squeeze farmers and to lock more growers into the behemoths' product bundles and digital agriculture platforms" (Kelloway, 2020, n.p.).

The practices outlined above all help link farmers to agricultural inputs and the firms supplying them, and in the digital era, they confer an additional advantage on the firms: digital decision support tools are typically based on machine learning, which uses big data, and it is claimed that the more data they collect, the more their predictive capacity improves. Rebate and incentive mechanisms thus might translate into additional value for companies like Bayer, which collect ever more farm data, leading to a competitive advantage in this new market. Thus, in the agricultural context, firms are investing in data collection and infrastructure (including legal infrastructure) on the basis of the (partly unfulfilled) future "promise of precision" (Hackfort 2023, p. 7) that more data allows for more accuracy in predictions and recommendations generated from big data. These predictions are not just sold to farmers; they also have unspecified future uses for the corporations holding the data (via copyright restrictions), which is a key characteristic of data assetization.

Price-Setting and Data Sharing

From historical research, we know that companies supplying farmers with seeds and chemicals have engaged in discriminatory pricing, arbitrarily setting higher prices for demographics or regions which are seen to depend on these products (Clapp, 2022). Farmers' organizations like the Canadian National Farmers Union have collected evidence that input suppliers set prices to increase their profits at the expense of farmers, such that they capture any marginal returns a farmer may have seen in years where certain commodities traded high on the international market. This organization highlights how farmers are put at a disadvantage by the "corporate industrial complex" (NFU, 2020) and calls for an investigation into the practices of firms that are part of fertilizer oligopolies (Nutrien, Yara, CF Industries, and Mosaic; NFU, 2022). In Germany, 1500 farmers have joined a class-action lawsuit against agricultural wholesalers for illegal price-setting in the sale of pesticides; among the defendants will be Germany's largest agricultural retailer, BayWa (Schaal, 2023).

With agricultural data collection, it seems likely that powerful agribusinesses will use farm data (e.g. on yields) to generate additional predictions about particular commodities and, following the same logic they have historically employed, use this insight to set prices (Harris, 2022; WSJ, 2012). Although we did not find explicit evidence that corporations are using agricultural big data for pricesetting (or selling it for this purpose), our research shows that their legal policies generate enough room for them to do so without disclosing their actual data practices. Bayer's current privacy statement forecloses seed pricing based on the personal data of farmers using the CFV platform but does not prevent the use of farm data, which suggests that the company is keeping open the possibility of selling farm data to third parties and using it for pricesetting: "We collect information about you and your farm operation for the following reason: (…) For advertising and marketing purposes. (…) However, we will NOT use your personal data to price seed products to you or others, other than to offer you product discounts or make you aware of other offers or programs for which you may qualify, and we will not share your personal data with any non-affiliated third-party vendor or website owner for their own marketing purposes without your consent" (Bayer CFV, 2022). Bayer seems to have changed its data policy recently;

the text of the policy from 2019 clearly states that the company will not use any data (aggregated or otherwise) for seed pricing or to make speculative commodity trades (Bayer CFV, 2019). The 2021 version for the US market, however, states that Bayer does not use aggregated personal or farm data for any other purpose than to lower its business risk. This keeps the door open for assetization through speculative financial activities generated from the use of both types of data—personal and farm. These activities are not made transparent in the legal agreement. Notably, Bayer's End User License Agreements (EULAs) further allow the company to "access, use, reproduce, display, modify, and prepare derivative works based on your Customer Farm Data in order to provide the CFV Services and related support to you, for our internal operations and research and development purposes, and for other purposes set forth in this Agreement" (Bayer CFV, 2021). One of these "other purposes" is to use both non-aggregated and aggregated personal data and customer farm data for hedging: "It is our policy not to use Customer Farm Data or Aggregated or Anonymized Information derived from Customer Farm Data to make speculative commodities trades, other than hedging we may do during the normal course of business to manage risks associated with our own seed/commodity production operations" (Bayer CFV, 2021). Hedging involves investing using various financial instruments—including future contracts, purchases, and commodities sales—and, apparently, agricultural data, which the company uses without explanation. These speculative financial operations based on collected farm data are the most obvious form of agricultural data assetization.

Our analysis of the use agreements for data-based tools and platforms from several companies shows that, along with the internal use of data for pricing and investment, data sharing seems to be common across ag-tech companies, even if they confine sharing to aggregated and anonymized datasets (e.g. John Deere, Claas 365 Farm.net; Corteva Agriscience, CNH Industrial, Syngenta, and Farmers Edge). For instance, the CFV Privacy Policy from 2019 explicitly states that the company will not share or sell any data (Bayer CFV, 2019). But in the present version of the policy, such statements are omitted, the wording instead allowing for the sharing of any nonpersonal data—farm data, for instance—with third parties without farmer consent (Bayer CFV, 2022). After aggregation, or if technical specifications require an exchange of data with external service providers, companies retain the right to pass on anonymized data to a third party without informing the farmer or obtaining their prior consent, beyond their agreement to the technology's license agreement. John Deere's service agreement states: "We may combine your anonymized data with data from others and include your data in anonymized datasets. We may also share, in aggregate, statistical form, non-personal information with our partners, affiliates or advisors" (John Deere US, 2022). Who these partners, affiliates, or advisors might be is not elaborated on. Corteva Agriscience states: "We may use and disclose Other Information for any purpose, except where we are required to do otherwise under applicable law" (Corteva Agriscience, 2019). "Other information" in this case means data that does not reveal or suggest the user's identity—browser and device information or vehicle usage data, for instance, but also data about farmers' "agricultural operation" (Corteva Agriscience, 2019). Likewise, in using the BASF xarvio Field Manager app, farmers give their consent to "the reproduction of this Licensed Data and to grant third party access without limitations (including, but not limited to, for the purpose of continually improving algorithms in the field of digital agriculture)." The company uses the term "Licensed Data" to mean information including "but not limited to data on crops and types of plants, the planting date, field boundaries, soil preparation measures, crop protection measures including the products used, doses and times, and contact data and statistics regarding the use of the app (‘Licensed Data’)” (BASF xarvio, n.d.).

The relevance of these legal agreements became obvious in a recent case where the sharing and use of farm data by third parties for price-setting was widely suspected. The “farm real estate” start-up Tillable entered a partnership with The Climate Corporation, a farm data analytics firm owned by Bayer. Tillable’s online service brings together landowners and farmers to rent out land that previously was leased directly to farmers. This approach has caused concern among farmers, and things escalated publicly when CFV users disclosed having received from Tillable unsolicited offers to rent the land at a specific price creating the impression that Bayer and Tillable were misusing farmer data to set land prices (Janzen, 2020). After heavy public criticism, the two companies canceled their partnership (Charles, 2020). Even if Tillable has publicly denied having accessed the data from Bayer’s platform, this case clearly shows the potential for farm data to be used for private gain in situations where doing so is not legally foreclosed. This again illustrates key mechanisms of data assetization in the agricultural sector, made possible, on the one hand, by farmers’ lack of rights in relation to their data (or data they help to collect) and, on the other, by firms establishing particular practices via use and license agreements that grant them exclusivity to big datasets, which is likely to eventually serve their assetization interests.

One peripheral industry in particular stands to benefit from legal agreements leaving open the possibility of aggregated datasets being shared or sold: insurance. The importance of managing risk in agricultural production is growing considerably. In the era of big agricultural data, insurance firms can not only look to historical weather data and a farmer's history—say, the average growth, in bushels, of wheat on a farm in a particular region—but also use big data and algorithms to predict the likelihood of losses almost in real time, using the information to validate present investments and drive future ones. Theoretically, "data-driven" predictions could enable these companies to make shrewder investments. Agribusinesses have formed strategic alliances with insurance firms such as Farmers Edge and Munich Re (Farmers Edge, 2022). Advertising aimed at investors boasts about such alliances and the uses of predictive analytics and big data; for example, IBM advertises its artificial intelligence, Watson, as participating in this predictive reinsurance industry (Bronson, 2022, p. 132). Furthermore, Farmers Edge Inc. recently launched a wholly owned subsidiary, DigiAg Risk Management, which will provide farmers across Canada with new parametric insurance products (Farmers Edge Inc., 2022). With satellite data, insurers can now more precisely analyze the condition of crops before and after they sustain damage. However, in certain cases, including countries where relevant data is either unavailable or not sufficiently transparent, traditional crop insurance with individual loss assessment is uncommon. Here, index-based insurance is offered as a solution. This insurance, based on digital technologies that support the modeling of crop yields using remote sensing, data analytics, and artificial intelligence, relies on a yield index to ensure crops "automatically pay out if the actual yield falls below an agreed percentage of the yield guarantee" (Munich Re, n.d.). One online advertisement for the insurance company Swiss Re reads, "Reinsurance and insurance companies will price their products better. Watson reads millions of pages of data, including unstructured data like discussion notes, contracts or tickets to help Swiss Re assess risk factors and make more informed decisions regarding price-risk accuracy. This helps Swiss Re reduce costs while increasing quality" (IBM, n.d.). Our analysis shows that it is very difficult to follow data from point of collection to management and use by private businesses; however, license agreements include clauses that would allow farm data, once aggregated, to be used for price-setting. Use agreements allow farmers access to their raw data only until it is "aggregated or anonymized." Aggregated datasets and information generated from them are inaccessible, fully owned by the firms and thus open to any of the methods of assetization outlined in this article.

Product Development and Targeted Marketing

In the analog era, companies predominantly used internal research and development to drive products; today, big data is essential to the process. For example, John Deere's See & Spray technology uses a machine-learning algorithm to identify weeds, allowing for site-specific herbicide spot spraying rather than broadcast spraying techniques. As with many machine-learning algorithms, the images produced by See & Spray's cameras are used to improve its weed identification models (John Deere, 2023). The collection of data for the sake of constantly improving algorithmic models is crucial to the ag-tech assetization business model. Another example of data use for product development and improvement is "predictive maintenance," a service offered by machinery manufacturers such as John Deere and Claas. Most John Deere construction equipment is outfitted with telematics software that captures various machine metrics, such as location, usage hours, temperature, and fuel consumption. This data is transmitted to the cloud in real time and purportedly used by John Deere to improve the performance of its products by allowing analysis of data on driver behavior or engine load (Prime, 2022). Within the predictive maintenance framework, the company provides incentives for farmers to allow data about their farm operations and land machines to be tracked in exchange for the promise of a perfected machine. When problems are detected, “expert alerts” are activated (John Deere US, 2023a) and farmers can use the Service ADVISOR Remote tool to enable dealers to remotely access their machine through the company’s Operations Center or the JDLink Dashboard (John Deere US, 2022). This predictive maintenance framework is based on contracts that offer, as a service to farmers, to monitor the condition of equipment in use and provide for timely maintenance. While the farmers who adopt it seem comfortable with this model, in effect, they pay for it at least twice, with one of these payments made in-kind, through the free provision of data via their machinery. Yet such data clearly helps the company improve its products and gain a competitive advantage in the market. The collection and analysis of agricultural data to generate data revenues from predictive services is a mechanism defined as key for assetization by scholars working in big data studies outside of agriculture.

For companies like John Deere, an additional benefit of predictive maintenance is the further strengthening of its relationships with its clients—or, put differently, of farmers’ dependence on the company’s machinery and services. Crop and other agronomic data are also used to improve existing products and services, make established business models more profitable, and bring new data-based services to the market. Corroborating this is our analysis of John Deere’s privacy statement, wherein the farmer agrees that the company can access and use machine agronomic data and machine-specific data in “anonymized and aggregated form for statistical purposes as well as to improve or enhance the services provided under this agreement, develop additional or new John Deere products and services, and/or identify new usage types of equipment” (John Deere EU, 2020). Similar language is common across legal agreements in the industry. AGCO states that farm data will be used in “on-going product development and improvement initiatives" (AGCO, 2019). Bayer's CFV privacy statement similarly illustrates the company's collection of personal data "and data on farm operations" for "research and development purposes, such as to improve Climate and Bayer's agronomic or scientific knowledge [or] develop and improve our products and services" (Bayer CFV, 2022).

Companies have historically sold their products to farmers via conventional mechanisms, like trade journals, newspapers, and broader (e.g. web-based) advertising, and, in a more targeted way, by sending agricultural advisors to offer farmers advice. In the digital farm era, companies use machinery and agronomic data to improve and market their products and services; analyzing license agreements, we found that in their EULAs, firms usually grant themselves the right to use clients' farm data to do so. For instance, by using BASF xarvio Field Manager app, farmers agree that "data on crops and types of plants, the planting date, field boundaries, soil preparation measures, crop protection measures including the products used, doses and times, and contact data and statistics regarding the use of the app ('Licensed Data')" can be used by BASF for "the development, manufacturing, enhancement, and/or marketing of products and services" (BASF xarvio, n.d.). Companies now have access to detailed data on clients' farming operations, including their purchases and use of commodities such as seeds, chemicals, and other inputs. Theoretically, this means that companies are better positioned to sell products by making more precise and relevant recommendations. Raven Inc.'s EULA states that advertisements may be targeted to users based on data that has been uploaded to the Raven Industries platform (Raven Industries, n.d.). Again, in the EULA, data is legally configured as an asset, granting the corporation control over the data and assuring future revenue streams from users.

Bayer explicitly pitches this targeted marketing strategy as part of its new assetization business model—one based on "predictive seed selection and placement" (Burwood-Taylor, 2021, p. 2) which seems advantageous to farmers, who get more targeted advice. A few years ago, the then head of research at Monsanto described in a positive light the digital synergies that would emerge once Bayer and Monsanto's disparate product portfolios were combined as part of the 2018 merger, saying: "In a few years, we want to send farmers a satellite image of their field once or twice a day to track crop growth and give an early warning if there's a problem somewhere with fertilizer, water, disease, or insects. And then they can find a solution with Bayer products" (CGB, 2019: n.p., own translation from German).

One specific example of a targeted recommendation uncovered by our analysis is Bayer's Seed Advisor, a digital tool purportedly developed to select—from Bayer's own product ecosystem—the hybrid corn most suitable for farms' specific locations (Bayer, 2018). Note that, according to its own press release, Bayer offers exclusively hybrid varieties that, unlike seed-stable plants, farmers cannot regrow but instead must purchase anew every year (Bayer, 2018). Seed Advisor is primarily aimed at seed dealers and retailers, who pass on input recommendations to farmers. After the Bayer/Monsanto merger, The Climate Corporation's Seed Advisor now provides farmers with recommendations for "best-performing" hybrid seeds based on Bayer's seed genetics library and "regional seed performance data" (Claver, 2019, n.p.; CGB, 2019). According to the company, benefits for farmers are significant and could lead to considerable yield increases (Maurin, 2019).

Despite its benefits to farmers, critics see such targeted marketing (a form of data assetization) and precision recommendations as further locking farmers into a state of dependency and into companies' product ecosystems. One criticism is that this targeted advice steers farmers only toward a particular company's proprietary seed varieties, limiting their options and potentially resulting in a lack of crop diversity. Critics also highlight the potential for agrochemical companies to use the data they collect to target farmers with offers and information which is misleading, inaccurate, or more beneficial to companies than to farmers. Overall, there is concern that companies with large amounts of data may significantly influence farmers' decisions: "The greater the amount of data that an agrochemical company has at its disposal, the more targeted the bait offers and bogus information on the farmers' screens" (CGB, 2019, p. 10–11; Maurin, 2019). According to the Open Markets Institute, "Farmer data collection and digital agriculture programs owned by agrochemical manufacturers result in farmers getting management recommendations from corporations with a vested interest in selling more agrichemicals" (Kelloway, 2022, n.p.). Notably, companies' vested interest in advice promoting their own products is arguably less visible to farmers in the digital era: the advice (or, in CFV's case, "prescriptions") of decision support platforms is putatively "data-driven" (i.e. algorithmically derived) and therefore has the connotation of sitting outside of human and economic interests. The distinction between a decision platform and a retailer or extension agent giving farmers advice on which inputs to use is the former's air of objectivity (Bronson, 2022). Put differently, many farmers are likely to trust in the decision platform's neutrality and follow its advice—in contrast to the skepticism they might feel toward any human farm adviser a company might send.

Discussion

Through the lens of assetization, we have examined corporate strategies for transforming agricultural data into value. Our analysis contributes empirically to the data studies literature by identifying three main agricultural data assetization strategies: securing relationships and dependence, price-setting and data sharing, and product development and targeted marketing.

Assetization in agriculture is largely based on gathering as much data as possible from different sources as a source of (future) value—and on securing the ability to do so. Scholarly work in data studies has outlined three ways to extract value from personal data collected online: data holders can access big data; data specialists can "mine" it for insights that strengthen their competitive position in the data market; and data strategists—that is, firms powerful enough to do so—can flexibly orient their corporate practices by extending data insights to as-yet-undefined novel applications (Mayer-Schönberger & Cukier, 2013). Our analysis shows that similar processes are at work in the agricultural sector, where already powerful input supply companies now have the means to assetize and profit from farm-level data. Big agricultural data is an intangible resource, an income-generating asset for those who control quantities of data and are able to further process it. Accordingly, agricultural companies, like other Big Tech firms, currently collect as much data as possible to develop products and services such as predictive seeding. To ensure the flow of data, they develop agricultural platforms that stream farm data directly from machines. They create incentives and lock-ins that make the full functionality of data-based decision support tools like Bayer's CFV contingent on farmers uploading their data, or that, like John Deere tractors, foreclose any other option. Monopolization, according to Birch & Muniesa (2020), is a key feature in the assetization process. Our analysis shows that in agriculture, just as in other spheres, platforms have become increasingly important to help establish relationships of monopoly, which partly explains why almost every agricultural firm offers its own platform. Furthermore, our analysis shows that key features of data assetization are present when agricultural data collection and valorization are made possible through policy and regulatory frameworks that protect trade secrets, allowing for obfuscatory practices and for companies to "protect" data as their own intellectual property (Birch, 2020). Companies are not required to disclose how they use the farm data they collect after it has been anonymized and aggregated. And license agreements are used as legal tools to obstruct access to data and, thereby, the ability of external observers (including big data studies researchers) to test and validate algorithms. Artificial intelligence and decision platforms are "pernicious black box[es]" (Pasquale, 2015) protected from critical oversight by intellectual property rights, copyright, and trade secrecy law—key elements of assetization dynamics (Birch, 2020, p. 4). Ultimately, it is impossible to test the validity of these platforms, the accuracy of AI-generated recommendations, or whether these recommendations work as claimed or are biased toward incommensurate corporate gain (i.e. toward recommending in-house products). Moreover, the publicly available license agreements, terms of use, and privacy statements we analyzed for this article were uniformly very difficult to understand. We believe that this obfuscation is a key element enabling assetization—complex language, inconsistent terminology, and references to different types of data in the legal statements likely make it difficult for farmers to comprehend the use of farm data.

We conclude that the three strategies of agricultural data assetization overlap and partly reinforce each other's effects. For instance, Bayer's "outcome-based" pricing program not only allows the firm to profit from adding such digital services to its portfolio but also helps to secure existing dependencies and relationships with farmers, whose data helps feed this new business model. Furthermore, we observed that often, the three forms of assetization are employed along with "traditional" forms of commodification. Bayer's predictive seed selection and placement, for example, is not just a new, assetization-based business model that sells predictions along with the company's seeds. It also secures Bayer's relationships with farmers and appears to help lock them into its product ecosystems, future data collection, and a state of dependency. Here, we see that the assetization of data complements rather than replaces commodity production and the commodification of tangible goods such as seeds, thus working to reinforce long-standing historical patterns of corporate control over farmers and, ultimately, the entire food system trajectories (Clapp, 2021).

Data assetization in agriculture furthers both continuity—building on the existing dependencies and power asymmetries between agribusinesses and farmers—and change in food system power relations. Most important here are the numerous platforms, all with subscription models and monthly fees as an important part of their business strategy and key to corporate revenues (e.g. Farmers Edge Inc., 2022). Additionally, although the strategies we have identified relate to novel digital technologies in a variety of forms (apps, platforms, and hardware), they all work toward servicing a high degree of concentration in not only big agricultural data and centralized data infrastructure but also market power in the food system (Prause et al., 2021). Smaller start-ups being bought off by larger corporations are common in the ag-tech industry—a prime example is Monsanto's purchase of The Climate Corporation in 2014. The concentration of power related to these technologies is a long-standing and well-known pattern in agriculture. Compared to Big

Tech firms like Amazon and Google, powerful agribusiness and ag-tech companies are uniquely positioned to benefit from data assetization. Agribusinesses have unique capabilities because for almost a hundred years, they have shaped the development of technology to control farmers and allow capital to infiltrate into farming—what political economists of agriculture call "appropriationism" (Goodman and Redclift, 1994; Stone, 2022b). These long-standing relations of dependence have also fostered the uptake of proprietary products that have further tied farmers to technologies and companies. In contrast to other fields, where data is transformed into value via assetization strategies such as personal data collection, assetization strategies in agriculture build on historical relationships and patterns of power that are by now incredibly solidified (Bronson & Sengers, 2022).

However, we also observe a fundamental transformation in agriculture, with new actors entering into the field. For instance, Google's parent company, Alphabet Inc., has recently invested in Mineral, a project that, according to news reports, has already collected data on 10% of the world's farmland (Marston & Burwood-Taylor, 2023). Furthermore, agribusinesses are now partnering with classic tech companies to expand their digital capabilities and datasets and, thus, the reach of their assetization strategies. New partnerships between Big Tech players and agribusiness firms can be assumed to generate revenue from assets of different types and to be mutually beneficial, like the cooperation between Microsoft and Bayer (two firms that control large amounts of agricultural data) on Microsoft's Azure Data Manager (Marston & Burwood Taylor, 2023). Thus, while assetization is a broader phenomenon described by data studies scholars, assetization in agriculture, given the sector's historical political economy, shows unique features when examined empirically. As such, this empirical examination of the assetization of farm data provides to big data studies broader insights on assetization processes, reinforcing the importance of looking at big data practices in ways that are attuned to potential specificity across forms of data and across sectors.

Conclusion

We have empirically studied and systematically described three strategies with which input supply corporations create value from agricultural data; all three fit within the larger pattern of big data's assetization. The strategies we have identified have socio-ecological implications; they affect social justice, food sovereignty, and sustainability, the latter of which does not always receive due attention in critical data studies (c.f. Gabrys, 2016; Goldstein & Nost, 2022). Our results indicate the reproduction of asymmetrical power relations in the agri-food system favoring corporations and the continuation of long-standing dynamics of inequalities. We can infer that the big data-based predictions agribusinesses sell to farmers are directed toward a productivist model of "surveillance agriculture" (Stone, 2022a) that reinforces existing patterns of unsustainable agro-industrial farming and renders other routes, such as agroecology, peasant farming, and organic farming less legitimate and possible.

Further work is needed, including research into effective regulation, which could ensure that the benefits of data assetization be equitably distributed between farmers, consumers, citizens, and those who control the data. Our analysis suggests that, even as farmers who adopt big data tools are likely to gain a competitive advantage over their neighbors via these tools' precision analytics, corporate actors currently stand to benefit incommensurately. Currently, it is input supply companies who collect and control the bulk of farm data and who stand to gain from future data uses, not farmers, because the governance context surrounding agricultural data grants these companies control. Despite differences among international jurisdictions, in most countries where the firms analyzed in this article have their headquarters, we observe a lack of state-level regulation of farm data. In the absence of effective regulation that specifically considers the unique relations surrounding agricultural big data, service and technology providers are setting their own rules for data use via internal policies and enforcing them through license and user agreements.

Furthermore, antitrust laws in the United States and the European Union have generally failed to prevent increasing corporate concentration in agriculture (e.g. allowing Bayer to acquire Monsanto). Yet in Europe, leadership has been shown in the context of data governance, an example of which is the General Data Protection Regulation. Thus, policy leaders could use the novel technological domain of digital agriculture as a starting point for legal reform and a broader restriction of oligopoly in food and farming. What is needed is a reshaping of not just how corporations harvest value from data in digital agriculture, but how they operate in relation to food sovereignty in the food system more broadly.

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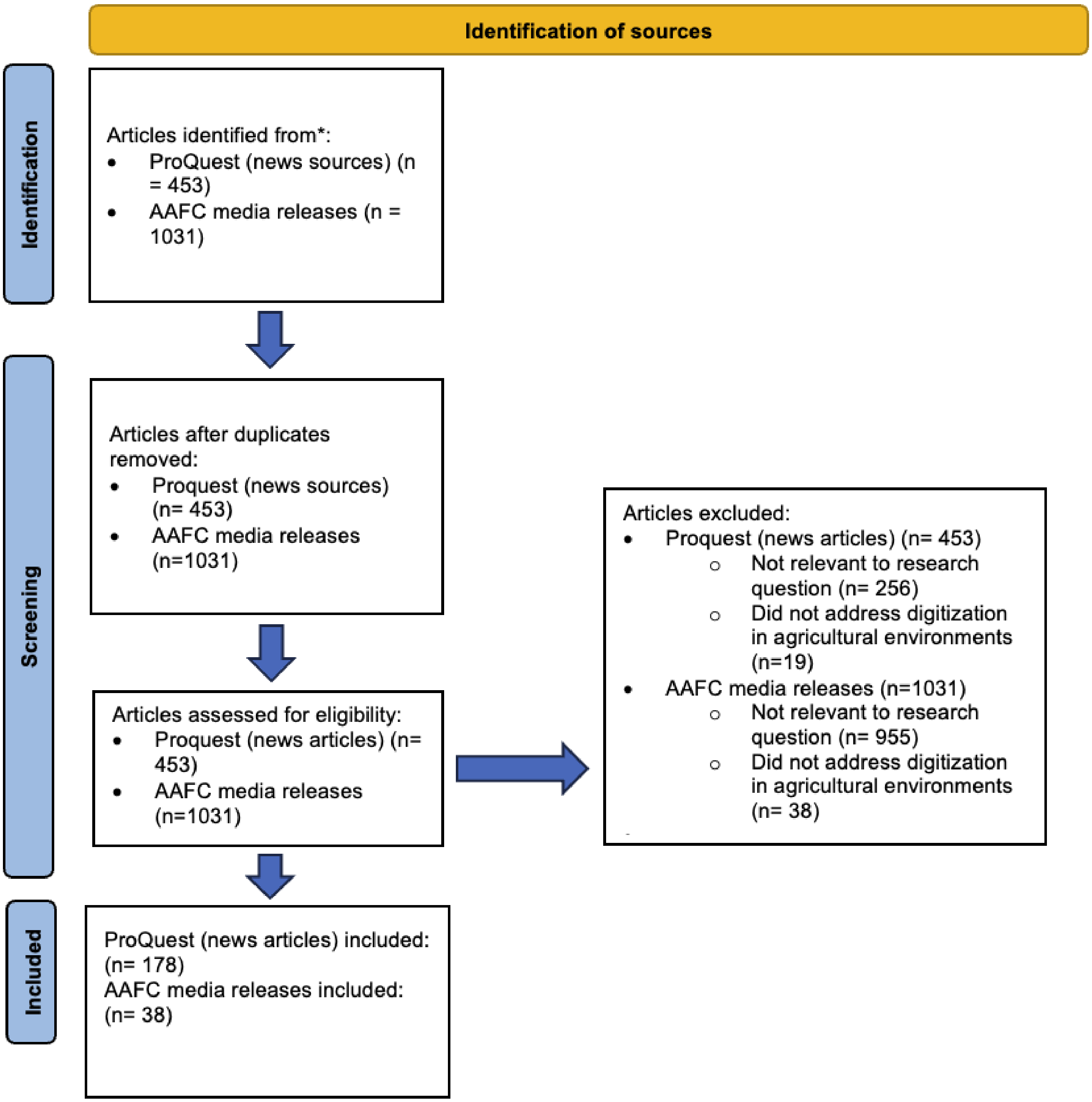
Appendices

Appendix A: Supplementary Material for Chapter 1

Appendix A.1: News Article Sources

Newspaper	**Region**	**Number of Articles Analyzed**
Globe and Mail	National	35
National Post	National	18
Toronto Star	Toronto, Ontario	6
Winnipeg Free Press	Winnipeg, Manitoba	49
Regina Leader Post	Regina, Saskatchewan	10
Chronicle Herald	Halifax, Nova Scotia	10
Calgary Herald	Calgary, Alberta	12
Telegraph-Journal	New Brunswick	6
Star Pheonix	Saskatoon, Saskatchewan	9
Times Colonist	Victoria, British Columbia	1
Edmonton Journal	Edmonton, Alberta	5
Vancouver Sun	Vancouver, British Columbia	3
Whig-Standard	Kingston, Ontario	2
Montreal Gazette	Montreal, Quebec	3
Ottawa Citizen	Ottawa, Ontario	3
Sudbury Star	Sudbury, Ontario	1
Windsor Star	Windsor, Ontario	3
The Province	British Columbia	2
TOTAL		**178**

Appendix A.2: Screening process for news articles and AAFC media releases



Appendix A.3: List of Government Documents Analyzed

	Government Document	Year	Publisher
1	Agri-Environmental Indicator Report Series: Report #4	2016	Agriculture and Agri-Food Canada
2	Agricultural Innovations	2017	Agriculture and Agri-Food Canada
3	The Path to Prosperity: Resetting Canada's Growth Trajectory	2017	Advisory Council on Economic Growth
4	Unlocking Innovation to Drive Scale and Growth	2017	Advisory Council on Economic Growth
5	Investing in a Resilient Canadian Economy	2017	Advisory Council on Economic Growth
6	Learning Nation: Equipping Canada's Workforce with Skills for the Future	2017	Advisory Council on Economic Growth
7	Growing Opportunity through Innovation in Agriculture	2017	Statistics Canada
8	A Portrait of a 21st Century Agricultural Operation	2017	Statistics Canada
9	AgriInnovate Program	2017	Agriculture and Agri-Food Canada
10	Canadian Agriculture: Evolution and Innovation	2017	Statistics Canada
11	Report of Canada's Economic Strategy Tables: Agri-Food	2018	Innovation, Science and Economic Development Canada
12	Federal-Provincial-Territorial Ministers of Agriculture: Progress Report on the Pan-Canadian Framework on Clean Growth and Climate Change	2018	Agriculture and Agri-Food Canada
13	Agriculture Clean Technology (ACT) Program	2018	Agriculture and Agri-Food Canada
14	Living Laboratories: Collaborative Program – Applicant Guide	2018	Agriculture and Agri-Food Canada
15	Clean Growth and Climate Change in Canada: Forestry, Agriculture and Waste	2019	House of Commons
16	Advancements of Technology and Research in the Agriculture and Agri-Food Sector that can Support Canadian Exports	2019	House of Commons
17	Agriculture and Agri-Food Mandate Letter, 2019	2019	Agriculture and Agri-Food
18	Canada's Changing Climate Report	2019	Government of Canada
19	Food Policy for Canada	2019	Agriculture and Agri-Food Canada
20	A Healthy Environment and a Healthy Economy	2020	Environment and Climate Change Canada
21	A Healthy Environment and a Healthy Economy [Annex: Climate-Smart Agriculture]	2020	Environment and Climate Change Canada

22	Agriculture and Agri-Food Mandate Letter, 2021	2021	Agriculture and Agri-Food
23	A Healthy Environment and a Healthy Economy: Update	2021	Environment and Climate Change Canada
24	Budget 2021	2021	Department of Finance
25	The Guelph Statement	2021	Agriculture and Agri-Food Canada
26	Agricultural Climate Solutions: Grant Application Guide	2021	Agriculture and Agri-Food Canada
27	Sustainable Agriculture Strategy: Discussion Document	2022	Agriculture and Agri-Food Canada
28	Agriculture and Agri-Food Canada's Strategic Plan for Science	2022	Agriculture and Agri-Food Canada
29	Canada's Methane Strategy	2022	Environment and Climate Change Canada
30	Canada's National Adaptation Strategy: Building Resilient Communities and a Strong Economy [for comments]	2022	Environment and Climate Change Canada
31	2023 Emissions Reduction Plan	2022	Environment and Climate Change Canada
32	Budget 2022	2022	Department of Finance Canada
33	Discussion Document: Reducing emissions arising from the application of fertilizer in Canada's agriculture sector	2022	Agriculture and Agri-Food Canada
34	Canada's National Pathways document [consultation draft]	2022	Agriculture and Agri-Food Canada
35	Agricultural Clean Technology Program: Research and Innovation Stream	2022	Agriculture and Agri-Food Canada
36	Agricultural Clean Technology Program: Adoption Stream	2022	Agriculture and Agri-Food Canada
37	2021-22 Consumer Attitudes Towards Innovative Agricultural Technologies Survey and Focus Groups: Final Report	2022	Agriculture and Agri-Food Canada
38	2022 Qualitative Research on Consumer and Producer Views Towards Sustainability in Agriculture: Final Report	2022	Agriculture and Agri-Food Canada

Appendix A.4: Initial Inventory of Themes

How does DA relate to environmental sustainability? (Positive)	DA will enable environmental sustainability (Explicit)	DA will provide farmers the infrastructure [digital platforms] upon which they can sell carbon credits. A carbon credit market would reduce emissions.

		DA will allow for the optimization of farming inputs like pesticides, herbicides and fertilizers.
		DA will help farmers identify risk areas for greenhouse gas emissions.
		DA will allow for the measurement of soil carbon.
		DA will help the agricultural sector deal with climate change impacts.
		DA would help overcome challenges in data collection which are needed to address sustainability problems.
		DA will help to reduce food loss.
		DA will enable transparency, so consumers will know the sustainability practices of the farms they are buying from.
		DA will enable the identification of diseases, pests and nutrients early, allowing for more directed intervention which will benefit the environment.
		DA will increase farm operators' predictive capacity, making them more resilient to climate change.
		DA will enable 4R fertilizer application. This will optimize fertilizer use, reducing runoff into the environment.
	DA will enable environmental sustainability (Implicit)	DA is a clean technology.
		DA is a climate-smart technology.
		DA is a best management practice .
		DA will allow farmers to make informed decisions, which will benefit environmental sustainability.
		DA will enable a 'digital twin' or a real time information about the farming environment. This will enable better decision making that considers the environment.
		DA will enable productivity growth that is environmentally sustainable.
		DA will improve the resiliency of Canada's agri-food sector.
		DA will optimize the supply chain.
		DA will help to produce more with less.
		DA is required for better yield, quality and sustainability outcomes.
How does DA relate to environmental sustainability? (Negative)	DA will not enable environmental sustainability	DA would help farmers make better, more environmentally-friendly decisions, but they are expensive.
		The decisions enabled by DA are not better than a farmer's intuition.

		DA does not always enable the farmer to access actionable information.
		DA would benefit sustainability, but it is not realistic for farmers without broadband.
		Investments being made into DA are being made with productivity, not sustainability, in mind.
		The outcomes of DA are uncertain.

Appendix B: Supplementary Material for Chapter 2

Appendix B.1: Interviewee Information

Interviewee	**Job Title**	**Notes**
IV.1	Technologist	
IV.2	Intermediary	
IV.3	Entrepreneur/Funder	Cut from dataset (not working in Canadian context)
IV.4	Technologist	Cut from dataset (not working in Canadian context)
IV.5	Entrepreneur/Funder	
IV.6	Funder	
IV.7	Entrepreneur	
IV.8	Intermediary	
IV.9	Funder/Entrepreneur	
IV.10	Funder/Entrepreneur	
IV.11	Intermediary	
IV.12	Funder	
IV.13	Funder	
IV.14	Technologist/Entrepreneur	
IV.15	Entrepreneur	
IV.16	Funder	
IV.17a	Intermediary	
IV.17b	Intermediary	
IV.18	Technologist/Entrepreneur	
IV.19	Entrepreneur	

Appendix B.2: Semi Structures Interview Questions - Ag-Tech Actor Interview Guide [Technologist/Entrepreneur]

1. Tell me about yourself…What do you do and how did you become involved in ag-tech?
2. Can you tell me about the company you work for and your role at this company?

3. What does a day in the life at work look like for you?
4. How did you come to do this work (training, background, journey)?
5. What products does your company provide for farmers/farm workers? What do these products help farmers do?
6. What kind of variables does your product impact or measure on the farm?
7. What kind of agricultural data is collected by your product? And what does that data collection help to achieve?
8. What kind of problems are you trying to solve in your work? Why are these problems significant?
   a. Environmental? Financial?
9. Why do you focus on XX variable (like yield)?
10. You mentioned the word "optimize" … what do you mean by that? Is that a word that is used often by others in your industry?
11. I'm really interested in this idea that precision agriculture technologies might help farmers make good decisions related to profitability, productivity *and* environmental sustainability. Do you focus on any of these aspects… maybe you focus on all of them?
12. Do you think that there could be any unintended consequences or negative impacts from using any of the ag-tech tools that your company develops?
13. If you were to invent an ideal precision agriculture tool (money and time wouldn't be an issue in this scenario), what would it help farmers do?
14. What does your ideal sustainable farm of the future look like to you (maybe 10 or 15 years in the future)?
    a. Possible follow-ups: What is the role of technology on this farm of the future? What are the roles of humans? Of animals/plants/non-living entities?
15. If your company is a start-up, how do you attract funding and resources?
16. Do you ever interact with the funders (have you ever been brought into a pitch to explain the technical side, for example)?
17. How important is the role of funders for your company or for you?
18. Is there anything else you'd like to share?
19. (*Snowball sampling*) Do you know anyone else with ag-tech expertise that works for an ag-tech start-up/firm that would be willing to talk to me?

Appendix B.3: Semi Structures Interview Questions – Ag-Tech Actor Interview Guide [Funder]

1. Tell me about yourself…What do you do and how did you become involved in ag-tech?
2. Can you tell me about the company you work for and your role at this company?
3. How did you come to do this work (training, background, journey)?
4. Do your company fund ag-tech companies? If so, how do you choose which ones you fund?
5. What kinds of agricultural technologies are important, do you think and why?
6. What problems exist in agriculture that deserve funding? How do you think that they technologies you fund might help solve these problems?
7. Are there any indicators that make you more likely to fund certain ag-tech companies? What kind of indicators are you looking for?
8. How important are productivity, or economic or environmental sustainability impacts from innovations in ag-tech?

9. If environmental sustainability is important, what kinds of environmental sustainability elements are you more likely to be drawn towards in terms of funding?
10. How important is scalability in the companies you fund? How do you decide whether a company is scalable or not?
11. Is the collection of big data an important feature that you look for when you're funding these companies? We hear a lot about how data is such a valuable resource, so I'm wondering whether it plays a role in funding decisions.
    a. Possible follow-ups: How do you think about data governance? Do you need to clarity regarding the ways the companies you fund might govern data that they collect?
12. If there was an ideal ag-tech company out there (you can use your imagination – perhaps this company doesn't exist yet) what would this company do? How would it impact agriculture?
13. If you were to invent an ideal precision agriculture tool (money and time wouldn't be an issue in this scenario), what would it help farmers do?
14. What does your ideal sustainable farm of the future look like to you (maybe 10 or 15 years in the future)?
    a. Possible follow-ups: What is the role of technology on this farm of the future? What are the roles of humans? Of animals/plants/non-living entities?
15. Is there anything else you'd like to share?
16. (*Snowball sampling*) Do you know of anyone else in the venture capital space that has experience funding ag-tech companies and who would be willing to talk to me?

Appendix B.4: Semi Structures Interview Questions – Ag-Tech Actor Interview Guide [Intermediary]

1. Tell me about yourself…What do you do and how did you become involved in ag-tech?
2. Can you tell me about the company you work for and your role at this company?
3. What do you see the role of [your company] in the ag-tech industry in Canada?
4. Do your company fund, mentor or consult with ag-tech companies/entrepreneurs? If so, how do you choose which ones you fund/mentor/consult with?
    a. Possible follow-up: If you are selective, what are your selection criteria?
5. What kind of mentorship/consulting do you/your company provide to entrepreneurs and/or funders in the ag-tech space?
6. What kinds of agricultural technologies are important, do you think and why?
7. How important to you think environmental sustainability, productivity, or financial factors are to the folks your consult with in the ag-tech industry?
    a. Possible follow-up: Do you think there are certain factors that are more important than others?
    b. Possible follow-up: Has environmental sustainability become more of a factor in the past decade? Or has it always been important?
    c. Possible follow-up: If environmental sustainability is an important factor, what elements of environmental sustainability come up more in your line of work?
8. How important is the concept of scalability with regards to the folks you consult with?
9. Do you have an example of a company that you've helped that's become successful? What product did they innovate? What was their story?

    a. In terms of successful companies, what kinds of problems are they solving? Are they solving sustainability issues?
10. Do you find that the collection of agricultural big data is a important factor for the folks you consult with?
    a. We hear a lot about how data is such a valuable resource, so I'm wondering whether it plays a role in the decisions of the people you consult with?
    b. How do you think about data governance?
11. If there was an ideal ag-tech company out there (you can use your imagination – perhaps this company doesn't exist yet) what would this company do? How would it impact agriculture?
12. If you were to invent an ideal precision agriculture tool (money and time wouldn't be an issue in this scenario), what would it help farmers do?
13. What does your ideal sustainable farm of the future look like to you (maybe 10 or 15 years in the future)?
    a. Possible follow-ups: What is the role of technology on this farm of the future? What are the roles of humans? Of animals/plants/non-living entities?
14. Is there anything else you'd like to share?
15. (*Snowball sampling*) Do you know of anyone else in the ag-tech innovation space that has experience funding or building ag-tech companies and who would be willing to talk to me?