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# **Digital agriculture: socio-technical-physical interactions and the transformation of the rural world(s)**

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# List of Abbreviations

AI	Artificial Intelligence
AIS	Agricultural Innovation Systems
BIPOC	Black, Indigenous, and People of Color
CA	Capabilities Approach
CT	Critical Theory
CVC	Coffee Value Chain
ES	Expert systems
ICA	International Coffee Agreement
ICO	International Coffee Organization
ICT4D	Information and Communication Technologies for Development
IoT	Internet of Things
LHDCs	Low Human Development Countries
ML	Machine Learning
OCAP	Ownership, Control, Access and Possession
PAR	Participatory Action Research
RI	Responsible Innovation
RTO	Return to Origin
SDGs	Sustainable Development Goals
SMS	Short Message System
SRI	System for Rice Intensification
UAV	Unmanned Aerial Vehicles
VRAT	Variable Rate Application Technology
GI	Geographical Indication
POD	Protected Designation of Origin
FNC	Federación Nacional de Cafeteros
OECD	Organization for Economic Cooperation and Development
FAO	Food and Agricultural Organization of the United Nations

# Executive summary

The social and environmental challenges that humanity faces today to produce food, fuel, and fibers in a sustainable and fair way call for a transformation. Digital agriculture has been embraced with much enthusiasm by many as the contour of such transformation. Proponents of these technologies, including international organizations as well as numerous researchers focused on innovations, describe this innovation as a paradigm shift. Associated with increased efficiencies and enhanced communication, digital agriculture is commonly depicted by these groups as the advent of a more sustainable and ‘smart’ future. Other groups, including grassroots organizations, socio-environmental activists, and critical scholars, on the other hand, see digital agriculture with skepticism and concern. They refer to the entrenchment of digital agriculture in productivist, capitalist, and extractivist forms of production, and a linkage with the consolidation of corporate power and state surveillance. Using a critical and systems approach, this thesis scrutinizes these arguments, examining the socio-technical transitions that emerge from agricultural digitalization, and discerns their societal and environmental consequences. This examination is relevant given that despite digital agriculture can transform the face of agricultural systems, it is not yet clear in what way. The emergent condition of digitalization requires this analysis to inform responsible governance of this innovation. Critical studies have made important contributions to this understanding. However, the complexity of digital agriculture calls for additional conceptual frameworks to be incorporated.

The coffee production system has been selected as a case study in this thesis. This selection responds to the global scope of this system and the relevance that it represents for rural development. To set the picture: coffee is one of the most traded agricultural products in the world. Yet, more than 70% of it is produced by smallholder farmers who receive less than 10% of its final value. Meanwhile, coffee farmers experience manifold social and environmental challenges that threaten their livelihoods and the sustainability of the whole system. Poverty, power and information asymmetries, and climate change are among them. Against this background, this thesis takes the perspective of coffee as a crop, a cultural system, and a value chain.

Following a qualitative research approach, the analysis is informed by a theoretical literature review and data from semi-structured interviews with developers and users of digital technologies. The thesis is divided into three studies (chapters 2, 3, and 4) which together present a critical analysis applied at three scales: 1) global, 2) value chain, and 3) local. Across these studies, three main socio-technical aspects of digital agriculture are addressed. First, global governance of digital agriculture and its consequences for farmers’

rights and capabilities. Second, the consequences of different technical assemblages for the sustainability of agricultural systems. Third, local forms of interaction with digital technologies.

After presenting an introduction in Chapter 1, Chapter 2 presents a literature review on the political dynamics of digital agriculture. Drawing upon an emancipatory conceptualization of agency and sovereignty, this chapter is focused on describing two main forms of governance: governance *through* and governance *of* digital technologies in the context of agriculture. This description is followed by an analysis of the multiple effects of these two forms of governance on farmer's sovereignty and agency. The analysis revealed that the governance of digital agriculture is an assemblage of multiple agencies of human and cyber agents (smart devices, automated machines, algorithms). Socio-technical interactions in this assemblage result simultaneously in sovereignty and agency gains and losses for farmers - a complex set of power transactions in which farmers participate many times inadvertently. Together with oppressive forms of governance associated with corporate technological lock-in, data extractivism, and a surveilling state, there is evidence also of a democratic facet of digitalization. This facet is integrated by open-collaborative networks, data cooperatives, cyberactivism, and open-source software. With this analysis, the study aimed to understand how the political position of farmers is affected by digitalization, understanding that this process is occurring in a context of structural power imbalance.

A socio-technical perspective is applied in Chapter 3 to explore 20 digital tools designed for the coffee value chain, examining the pathways toward sustainability (environmental, social, and economic) promoted by these tools. The socio-technical perspective mainly proposes that social and technical systems shape each other in reciprocal interactions. Building on this idea, the chapter examines the technical attributes of these tools (functionality, technologies included, operation rules, information flow). Subsequently, it analyzes the consequences of these attributes in terms of three broad social dynamics: 1) knowledge and value systems represented, 2) power structures, and 3) possibilities for using these tools effectively. The forms in which these social dynamics are shaped by these tools, in turn, yield specific sustainability outcomes. These include the kind of production systems that are endorsed - and not endorsed -, the access to these technologies and their benefits, and the way in which social inequalities and power asymmetries are addressed - or not addressed -. The data for this analysis comes from interviews with 15 developers of these tools and secondary information. The analysis shows that technical attributes play a fundamental role in directing the kinds of pathways toward sustainability that are made available for agricultural systems. Additionally, it shows that in some cases, rather than a revolution, digital agriculture can look like business as usual but tweaked.

Chapter 4 presents a local perspective on digitalization. Using data from interviews with 73 households in two selected coffee growing communities in Colombia, this chapter explores how they engage with digital

technologies. The study parts from the idea that important reality-design gaps in digital agriculture result from a lack of understanding and inclusion of local worldviews around digital technologies and farming. Amartya Sen's capabilities approach was adopted as the conceptual framework for the analysis. This framework posits that resources only become assets when they can be used by individuals to accomplish the life they value. For that reason, the analysis in this chapter was focused on first, understanding the elements that configure a valuable life for these communities, and next, understanding how they use digital technologies to support the accomplishment of this life. The underlying values of this local process of technological appropriation were compared with the values represented by broader narratives of digital agriculture. This offered a picture of the negotiations and tensions that occur when contrasting visions of farming, digitalization, and a desirable future, interface. Drawing upon a relational perspective, the local appropriation process is characterized by multiple negotiations between farmers' personal and collective goals, situated knowledge, institutional programs, and the agency of non-humans (e.g. land, plants, animals, machines). From these interactions emerge distinctive forms of digitalization and non-digitalization. This process of local appropriation revealed the critical view of farmers and agency, for example, by following a digitalization pathway that profoundly diverges from dominant imaginaries and discourses around digital agriculture.

By applying a systems approach and by integrating three frameworks into critical scholarship - (1) emancipatory conceptualization of agency and sovereignty, (2) Sen's capabilities approach, and (3) a relational approach - this thesis presents evidence of the complexity of socio-technical-physical interactions that lead to certain broad-mainstream and local-everyday digitalization pathways. These pathways, in turn, present particular societal consequences, such as the kind of agricultural worlds that are made possible, the interests that are represented in them, and the possibilities of participation for different social groups. More than a single trajectory, digital agriculture is a space of multiplicity and permanent emergence, also for reproducing current – not necessarily sustainable - models. For this reason, this thesis calls for abandoning notions of immutability, universality, and uniformity in development discourses, perspectives of rurality, and the generation of new technologies. Instead, it proposes to integrate a critical and systems-relational perspective into inclusionary innovation research and practice.

# Zusammenfassung

Die sozialen und ökologischen Herausforderungen, mit denen die Menschheit heute bei der nachhaltigen und fairen Produktion von Lebensmitteln, Brennstoffen und Fasern konfrontiert ist, erfordern eine Transformation. Die digitale Landwirtschaft wird von Vielen mit großer Begeisterung als Wegbereiter für einen solchen Wandel angesehen. Befürworter dieser Technologien, darunter internationale Organisationen und zahlreiche Innovationsforscher:innen, bezeichnen diese Innovation als Paradigmenwechsel. In Verbindung mit einer höheren Effizienz und einer verbesserten Kommunikation wird die digitale Landwirtschaft von diesen Gruppen häufig als Beginn einer nachhaltigeren und „intelligenteren“ Zukunft dargestellt. Andere Gruppen, darunter Basisorganisationen, Umweltaktivist:innen und kritische Wissenschaftler:innen, betrachten die digitale Landwirtschaft hingegen mit Skepsis und Sorge. Sie verweisen auf die Verankerung der digitalen Landwirtschaft in produktivistischen, kapitalistischen und extraktivistischen Produktionsformen sowie auf eine Verbindung mit der Konsolidierung von Unternehmensmacht und staatlicher Überwachung. Mit einem kritischen und systemischen Forschungsansatz untersucht diese Doktorarbeit diese Argumente, die soziotechnischen Veränderungen, die sich aus der Digitalisierung der Landwirtschaft ergeben, und ihre gesellschaftlichen und ökologischen Folgen. Solch eine Untersuchung ist relevant, da trotz der Tatsache, dass die digitale Landwirtschaft das Gesicht der Agrarsysteme verändern kann, noch nicht klar ist, in welcher Weise dies geschehen wird. Angesichts des sich abzeichnenden Digitalisierungstrends ist solch eine Analyse auch relevant, um eine verantwortungsvolle Steuerung von Digitalisierung zu gewährleisten. Obwohl kritische Forschung bereits wichtige Beiträge zu diesem Verständnis geleistet haben, erfordert die Komplexität der digitalen Landwirtschaft die Integration zusätzlicher konzeptioneller Rahmenbedingungen in der Forschung.

Für diese Doktorarbeit wurde der Kaffeesektor als Fallstudie ausgewählt. Diese Auswahl ist auf die globale Reichweite dieses Sektors und seiner Bedeutung für die ländliche Entwicklung, zurückzuführen. Um das Bild zu vervollständigen: Kaffee ist eines der am meisten gehandelten landwirtschaftlichen Produkte der Welt. Dennoch wird er zu mehr als 70 % von Kleinbauern erzeugt, die weniger als 10 % des Endwerts erhalten. Gleichzeitig sind Kaffeebäuer:innen mit vielfältigen sozialen und ökologischen Herausforderungen konfrontiert, die ihre Existenzgrundlage und die Nachhaltigkeit des gesamten Sektors gefährden. Zu diesen Herausforderungen gehören Armut, Macht- und Informationsasymmetrien sowie der Klimawandel. Vor diesem Hintergrund wird Kaffee in dieser Arbeit als Kulturpflanze, als kulturelles System und als Wertschöpfungskette betrachtet.

Die Analyse folgt einem qualitativen Forschungsansatz und stützt sich auf eine Literaturrecherche sowie auf Daten aus halbstrukturierten Interviews mit Entwickler:innen und Anwender:innen digitaler Technologien. Die Doktorarbeit ist in drei wissenschaftliche Studien (Kapitel 2, 3 und 4) unterteilt, die zusammen eine kritische Analyse auf drei Ebenen darstellen: 1) global, 2) Wertschöpfungskette, und 3) lokal. In diesen Studien werden drei soziotechnische Aspekte der digitalen Landwirtschaft behandelt: Erstens die globale Steuerung der digitalen Landwirtschaft und ihre Folgen für die Rechte und Möglichkeiten der Landwirte; zweitens die Folgen unterschiedlicher Kombinationen von Technologien für die Nachhaltigkeit landwirtschaftlicher Systeme; und drittens lokale Formen der Interaktion mit digitalen Technologien.

Nach einer Einleitung in Kapitel 1 wird in Kapitel 2 eine Literaturübersicht über die politischen Dynamiken der digitalen Landwirtschaft gegeben. Ausgehend von einer emanzipatorischen Konzeption von Handlungsfähigkeit und Souveränität konzentriert sich dieses Kapitel auf die Beschreibung zweier Hauptformen der Steuerung: Steuerung durch und Steuerung von digitalen Technologien im Kontext der Landwirtschaft. Dieser Beschreibung folgt eine Analyse der vielfältigen Auswirkungen dieser beiden Steuerungsformen auf die Souveränität und Handlungsfähigkeit der Landwirt:innen. Die Analyse ergab, dass die Steuerung der digitalen Landwirtschaft durch mehrerer menschlicher Akteur:innen und Cyber-Agent:innen (intelligente Geräte, automatisierte Maschinen, Algorithmen) erfolgt. Sozio-technische Interaktionen in dieser Steuerung führen gleichzeitig zu Gewinnen und Verlusten in Bezug auf Souveränität und Handlungsfähigkeit für Landwirt:innen – ein komplexes Geflecht von Machtbeziehungen, an denen Landwirt:innen oft unabsichtlich beteiligt sind. Neben repressiven Formen der Steuerung, die mit der technologischen Abhängigkeit von Unternehmen, Datenextraktivismus und einem überwachenden Staat verbunden sind, gibt es auch Anzeichen für eine demokratische Facette der Digitalisierung. Diese Facette zeigt sich durch offene, kollaborative Netzwerke, Datenkooperativen, Cyberaktivismus und Open-Source-Software. Mit dieser Analyse zielte die Studie darauf ab, zu verstehen, wie die politische Position der Landwirt:innen durch die Digitalisierung beeinflusst wird, und dass dieser Prozess in einem Kontext systemischer Machtungleichgewichte stattfindet.

In Kapitel 3 wird eine soziotechnische Perspektive angewandt, um 20 digitale Tools zu untersuchen, die für die Kaffee-Wertschöpfungskette entwickelt wurden, und die Wege zur Nachhaltigkeit (ökologisch, sozial und wirtschaftlich) zu untersuchen, die durch diese Tools gefördert werden. Die soziotechnische Perspektive geht hauptsächlich davon aus, dass sich soziale und technische Systeme in wechselseitigen Interaktionen gegenseitig beeinflussen. Aufbauend auf dieser Idee untersucht die Studie die technischen Eigenschaften der Tools (Funktionalität, enthaltene Technologien, Betriebsregeln, Informationsfluss). Anschließend werden die Auswirkungen dieser Eigenschaften in Bezug auf drei große soziale Dynamiken analysiert: 1) die dargestellten Wissens- und Wertesysteme, 2) die Machtstrukturen und 3) die Möglichkeiten für eine

effektive Nutzung dieser Tools. Die Formen, in denen diese sozialen Dynamiken durch die Tools geprägt werden, führen wiederum zu spezifischen Nachhaltigkeitsergebnissen. Dazu gehören beispielsweise die Art der Produktionssysteme, die unterstützt werden – und die, die nicht unterstützt werden –, der Zugang zu den Technologien und ihren Vorteilen sowie die Art und Weise, wie soziale Ungleichheiten und Machtasymmetrien angegangen werden – oder eben nicht angegangen werden. Die Daten für diese Analyse stammen aus Interviews mit 15 Entwicklern der Tools und aus Sekundärdaten und -informationen. Die Analyse in diesem Kapitel zeigt, dass technische Eigenschaften eine grundlegende Rolle dabei spielen, welche Wege zur Nachhaltigkeit für landwirtschaftliche Systeme verfügbar gemacht werden. Darüber hinaus zeigt sich, dass die digitale Landwirtschaft in einigen Fällen eher wie ein „Business as usual“ aussehen kann, das nur geringfügig angepasst wird, als wie eine Revolution.

Kapitel 4 präsentiert eine lokale Perspektive auf die Digitalisierung. Anhand von Interviews mit 73 Haushalten in zwei ausgewählten Gemeinden kolumbianischer Kaffeebäuer:innen wird in diesem Kapitel untersucht, wie sie mit digitalen Technologien umgehen. Die Studie geht von der Idee aus, dass wichtige Lücken in der Gestaltung der Realität in der digitalen Landwirtschaft auf mangelndes Verständnis und mangelnde Einbeziehung lokaler Weltanschauungen in Bezug auf digitale Technologien und Landwirtschaft zurückzuführen sind. Der Fähigkeiten-Ansatz von Amartya Sen wurde als konzeptioneller Rahmen für die Analyse übernommen. Dieser Ansatz geht davon aus, dass Ressourcen nur dann zu Vermögenswerten werden, wenn sie von Einzelpersonen genutzt werden können, um das Leben zu führen, das sie wertschätzen. Aus diesem Grund konzentrierte sich die Analyse in diesem Kapitel zunächst darauf, die Elemente zu verstehen, die ein wertvolles Leben für diese Gemeinschaften ausmachen, und dann darauf, zu verstehen, wie sie digitale Technologien nutzen, um dieses Leben zu unterstützen. Die zugrunde liegenden Werte dieses lokalen Prozesses der technologischen Aneignung wurden mit breiteren Narrativen der digitalen Landwirtschaft verglichen. Diese Analyse bot ein Bild der Verhandlungen und Spannungen, die auftreten, wenn unterschiedliche Visionen von Landwirtschaft, Digitalisierung und einer wünschenswerten Zukunft aufeinandertreffen. Ausgehend von einer relationalen Perspektive ist der lokale Aneignungsprozess durch vielfältige Verhandlungen zwischen den persönlichen und kollektiven Zielen der Landwirt:innen, dem situierten Wissen, den institutionellen Programmen und der Handlungsfähigkeit nichtmenschlicher Akteur:innen (z. B. Land, Pflanzen, Tiere, Maschinen) gekennzeichnet. Aus diesen Interaktionen ergeben sich unterschiedliche Formen der Digitalisierung und Nichtdigitalisierung. Der Prozess der lokalen Aneignung offenbarte die kritische Sichtweise der Landwirt:innen und ihrer Handlungsfähigkeit, beispielsweise indem sie einen Digitalisierungsweg beschritten, der sich grundlegend von den vorherrschenden Vorstellungen und Diskursen über die digitale Landwirtschaft unterscheidet.

Durch die Anwendung eines systemischen Ansatzes und die Integration von drei Rahmenbedingungen in die kritische Wissenschaft – (1) emanzipatorische Konzeptualisierung von Handlungsfähigkeit und Souveränität, (2) Amartya Sen's Ansatz der Fähigkeiten und (3) ein relationaler Ansatz – liefert diese Arbeit Belege für die Komplexität sozio-technisch-physischer Interaktionen, die zu bestimmten breiten Mainstream- und lokalen alltäglichen Digitalisierungspfaden führen. Diese Pfade wiederum haben besondere gesellschaftliche Auswirkungen, beispielsweise auf die Art der landwirtschaftlichen Welten, die sich entwickeln, auf die Interessen, die in ihnen vertreten werden, und auf die Möglichkeiten der Beteiligung verschiedener sozialer Gruppen. Die digitale Landwirtschaft ist mehr als eine einzelne Entwicklung, sie ist ein Raum der Vielfalt und des permanenten Entstehens, auch für die Reproduktion aktueller – nicht unbedingt nachhaltiger – Modelle. Aus diesem Grund fordert diese Doktorarbeit dazu auf, Vorstellungen von Unveränderlichkeit, Universalität und Einheitlichkeit in Entwicklungsdiskursen, Perspektiven des Ländlichen und der Generierung neuer Technologien aufzugeben. Stattdessen schlage ich vor, eine kritische und systemrelationale Perspektive in die Innovationsforschung und -praxis zu integrieren.

# 1. Introduction

Three agricultural revolutions have taken place since *Homo sapiens* began roaming the earth approximately 300,000 years ago: settled agriculture, the British Agricultural Revolution, and the Green Revolution. Some argue that, from the hands of technologies such as computers, global positioning systems, sensors, and the internet, we could be experiencing the next of these revolutions. This is not surprising, given the novel forms of information management that come with these technologies. New possibilities that can create unprecedented forms of knowledge, and unique forms of interaction between humans, plants, animals, machines, and programs, transforming radically the face of agricultural systems.

Despite the significant achievements of these previous revolutions, the challenges that humanity faces today to produce food and fibers in a sustainable and fair manner call for a transformation, especially given the current context of growing environmental pressure. It is mentioned that, to produce enough healthy and affordable food, while also preventing further degradation of ecosystems on which we depend to subsist, the global agrifood system requires a new approach to food production, distribution, and consumption (Ingram & Ericksen, 2010). Consequently, governments are seeking to implement strategies to meet global goals on biodiversity, climate change, and food systems proposed in the Convention on Biological Diversity agreed upon at the United Nation's Climate Change Conference (COP26) and the Food Systems Summit (UNFSS) (Jones et al., 2022).

Different authors have expressed the view that digital agriculture may represent this transformation (Emeana et al., 2020; Mehrabi et al., 2018; Relf-Eckstein et al., 2019; Schwab, 2016; Walter et al., 2017; Woodard, 2017). For this reason, the process of digitalization in agriculture has also been described as 'Agriculture 4.0'. The revolutionary character of digital agriculture has been rationalized through the linkage between access to precise information, environmentally sound management (Lajoie-O'Malley et al., 2020), and enhanced productivity and efficiency (Howland et al., 2015; Rotz, Gravelly, et al., 2019; Tilman et al., 2011). It has even been argued that digital agriculture represents a paradigm shift from input-based to knowledge-based agriculture (Bongiovanni & Lowenberg-Deboer, 2004; Woodard, 2017). This shift is regarded as a step towards a new, more intensive, and sustainable agriculture (FAO, 2013), and as the new frontier of innovation (Relf-Eckstein et al., 2019) - one that allows to 'reimagine' farming to create a 'smart farming future'.

Beyond the questionable assumption that agriculture was not based on knowledge before digitalization, other authors warn that digital agriculture should not be considered a silver bullet to overcome the multiple

challenges of agriculture (Daum et al., 2022; Hackfort, 2023; Kimbrell, 2002). Moreover, for some other authors, more than a revolution, digitalization is supporting the status quo of the global industrialized models of production. For example, influential imaginaries and practices of digital agriculture have been linked to a productivist approach (Bronson, 2018; Kuch et al., 2020; Lajoie-O'Malley et al., 2020; Rotz, Gravelly, et al., 2019; Wolf & Wood, 1997) and blamed for reinforcing the use of synthetic inputs (Clapp & Ruder, 2020; Wolf & Wood, 1997), and the dominant position of already powerful actors (Bronson, 2018, 2019; Carbonell, 2016; Clapp & Ruder, 2020). Consequently, although digital agriculture has been called Agriculture 4.0 by some, it has also been referred to as the 'Green Revolution 2.0' by others (Klerkx & Rose, 2020).

These different positions coexist because digital agriculture is a complex socio-technical phenomenon, that not only provides space for multiple interpretations but is also prone to produce multiple plausible trajectories with specific social and ecological consequences. Given that it is a relatively novel transformation, these potential trajectories, and their institutionalized effects on agricultural systems remain mostly uncertain (Clapp & Ruder, 2020; Fraser, 2019; Klerkx & Rose, 2020). Precisely this uncertainty motivated this research. The growing ubiquity of digitalization in different agricultural systems and the far-reaching opportunities and risks that it entails, demand a better understanding of this innovation process in all its complexity. Given the emergent condition of digital technologies, building this kind of understanding is imperative to guide the development of responsible governance systems in the context of digital agriculture. The overall goal of this thesis is to examine the kind of socio-technical transitions that digital agriculture is enabling, as well as the implications for society and the environment that result from these transitions. To achieve this, it is necessary to increase the theoretical and empirical knowledge about digitalization using a systems and critical approach. Following this systems and critical approach, this thesis addresses three main socio-technical aspects of digital agriculture. First, the global governance system of digital agriculture and its consequences for farmers' rights and capabilities. Second, sustainability pathways enabled by the technical assemblages of digital agriculture technologies. Third, local forms of using these technologies to achieve human development.

## **1.1. Framing digital agriculture**

Digital agriculture can be broadly defined as the process of applying digital technologies and digital information throughout the different stages of agricultural value chains. This definition, however, is not completely useful for grasping the full spectrum of technical and social processes associated with digitalization. Neither does it account for the complex network of technologies, actors, and agri-food processes that underpin digital agriculture, or their manifold interactions. For instance, the complex array

of different digital technologies has prompted the use of categories to better understand what is included when we talk about digital technologies. Such is the case of distinguishing digital technologies embodied in physical devices from digital technologies that are only software (disembodied) (Birner et al., 2021). Full taxonomies have been proposed based on technical features of technologies such as functionality, information flow, interactivity with other technologies, and the domain where they operate (physical, cyber, cyber-physical) (Berger et al., 2018; Roeglinger et al., 2016). Digital technologies can also be described according to the type of service they address (e.g. advisory services, financial services, farm tools, access to markets) (Porciello et al., 2022), or their focus area (e.g. productivity, plant health, animal well-being, transaction costs) (Rolandi et al., 2021). Additional attributes to designate digital agriculture technologies include the type of farmer or farming system to which the technology is oriented (e.g. large-industrialized farms, smallholder farms, conventional production, agroecological farms), the stage in the value chain where the technology operates (production, processing, trade, consumption, monitoring), or the space where the action of digital technologies is centered (on-farm and off-farm).

From these different classifications of digital technologies, it becomes clear that rather than a single category, digital technologies should be understood as a diverse group, with each technology presenting different technical attributes and forms of integration into agri-food systems. This awareness is relevant to better understand the complexity of interactions between technical, social, and environmental systems, and the diverse forms in which digital technologies are integrated into agriculture. For example, relatively simple digital technologies such as Short Message Services, hotlines, databases, mobile telephony, and digital social networks, are commonly associated with the provision of generic information to smallholder farmers that participate in commodity markets. More sophisticated technologies such as environmental sensors, artificial intelligence (AI), machine learning, big data, the Internet of Things (IoT), cloud computing, robotics, unmanned aerial vehicles (UAV), variable rate application technology (VRAT), and blockchain, can provide more precise information at the farm level, even in a millimetric scale. Another important feature of digital agriculture is that more often operates in assemblages formed by distinct technologies. In these assemblages, some technologies can interact with others without the mediation of any human actor. Such is the case with algorithms, smart devices interconnected through IoT or automated sensors.

Regarding the technical affordances provided by digital technologies, multiple applications of these different technologies have been conceptualized and reported in the literature. In terms of monitoring agricultural conditions, these technologies allow for the diagnosis of pests, diseases, soil conditions, or maturation stages, the determination of livestock conditions and behavior, and the prediction of weather conditions and yield (Aqeel-ur-Rehman et al., 2014; Khanal et al., 2017; Lajoie-O'Malley et al., 2020; Sharma et al., 2020; Wolf & Wood, 1997). Through digital channels, farmers have access to different

sources of relevant information such as agricultural practices and innovations (Faure et al., 2012), market information (Aker, 2011; Emeana et al., 2020) or weather conditions (Gosnell et al., 2019). In return, all the possibilities of information exchange and the action of smart artifacts, and autonomous programs and machines, have the potential to increase productivity (Howland et al., 2015; Sharma et al., 2020), reduce productions costs (Kos & Kloppenburg, 2019; Relf-Eckstein et al., 2019; Walter et al., 2017), and, very importantly, reduce the environmental footprint of agriculture (Basso & Antle, 2020; Walter et al., 2017). Agricultural digital information is not only useful for farmers, as other actors such as extension services, input providers, governments, or financial institutions, can use it to provide their products and services (FAO, 2013; Namyenya et al., 2022), or to guide the development of agricultural policies (Ali et al., 2020; Ehlers et al., 2022). A relevant feature of digitalization is that not only human actors are users of information, but technologies themselves also use information as input to perform on the field with efficiency gains. This is the case for AI, IoT, UAVs, and VRAT (Green et al., 2021; Schirmer et al., 2021; Tzounis et al., 2017).

To better understand what entails digital innovation, the process can be accurately described as a new information regime. While agricultural practices, economic and political structures, and our relationship with food and land will likely undergo a transformation due to digitalization, what is more immediately changing is our relationship with information: its creation, collection, processing, sharing, and storage. Kos and Kloppenburg (2019) express that the model of information management of digital agriculture presents the following disruptive characteristics: 1) collection shifts from human actors to devices and sensors, 2) collection is not done periodically but in real-time, 3) a shift in the role of computer programs in the process of interpreting and acting upon information, 4) a shift from linear to multi-directional information flows. Another important shift associated with the flow of information is the changing role of farmers in information creation and exchange. Traditional agricultural extension models have been blamed for holding a linear top-down information diffusion approach, from ‘experts’ to farmers (Cundill & Fabricius, 2009; Steinke et al., 2021). In contrast, digital technologies are opening opportunities for more distributed participation, with farmers acting not only as receivers of information but also as active producers and distributors. Moreover, through their use of smart devices and sensors for precision agriculture, farmers (in many cases inadvertently) contribute with their practices to the pool of information known as agricultural big data (Carbonell, 2016; Fraser, 2019; Kritikos, 2017).

Nevertheless, digital agriculture is not only characterized by a set of technological arrays and information flows but it is also characterized by the network of social actors that participate in the governance of these technologies. The term Agricultural Innovation Systems (AIS) has been applied to describe the network of actors within and beyond agricultural value chains that participate in the governance of innovations through use, design, promotion, or regulation (Fielke et al., 2019; Kernecker et al., 2021; Klerkx et al., 2010). In this

regard, digital agriculture can be described as an innovation system characterized by its constellation of actors, each one presenting a different role. For example, Kernecker et al. (2021) report a group of 13 different categories of actors, including farmers, advisors, agri-tech firms, researchers, public authorities, and IT experts. Interestingly the authors identified that farmers are involved in three different roles (developer, supporter, end-user) and that constellations of actors and their interactions vary according to the technologies involved (Ibid). Birner et al. (2021) point out the relevant role of private firms within and outside agriculture (agricultural input firms, tech firms, start-ups) in driving the process of digitalization from the supply side. Additionally, the authors highlight the role of governments in developing a supportive environment for digital entrepreneurship and implementing regulations to avoid market concentration, and of researchers in providing scientific knowledge to support the development and application of digital tools (Ibid). Lioutas et al. (2019) expressed that agricultural digital data act as the ‘fabric’ that connects the sum of different social actors that participate as producers and users of this data, namely farmers, manufacturers, wholesalers, distributors, and consumers. Within these networks of actors, digital agriculture provides a window for the emergence of a new class of actors, ones with the capacity also to make decisions in the system and to influence other actors. It is the case of cyber-agents, the set of smart artifacts, automated machines, and algorithms, who are endowed with their forms of communication, interpretation, and action; in many cases replacing human action. These new agents with their automated action, not only represented in the digital world and over information flows but also act over different biophysical elements of the farm (e.g. land, plants, animals), draw the contours of new networks and interactions among actors. It would be fair to say that digitalization not only poses the potential to transform human-technologies and human-human interactions, but it also has the potential to transform the interaction of technologies and humans with non-human components of the farm. This understanding is very relevant to discerning the network of interactions that are established, transformed, and disrupted with digital agriculture, and for recognizing that this innovation process permanently connects technical, social, and biophysical spheres. Ultimately, it is through these interactions that digital agriculture manifests and gets its full meaning.

## **1.2. Why is it relevant to explore socio-ecological dimensions in digital agriculture?**

The digitalization of agriculture is no different from many other innovations in the sense that it can present great benefits for society while also carrying the risk of unintended and unwanted consequences, that although uncertain, must be expected to occur (Hoffmann-Riem & Wynne, 2002). Consequences that, in the context of digital agriculture, can be harmful to people, farms, plants, non-human animals, and ecosystems (Rijswijk et al., 2021). Agriculture has been at this crossroads before, and conflicting perspectives between the potential benefits and perils of technologies have unleashed controversies and

societal resistance in the past (Stilgoe et al., 2013). These controversies, in turn, have contributed to shaping particular positions respecting technologies and their inherent social dilemmas. For example, previous cases such as the use of agrochemicals (Carson, 2002), and genetic modification of organisms (Macnaghten, 2015) contributed to raising awareness that digitalization and its potential deep implications for agricultural systems should be taken with caution (Rotz, Gravelly, et al., 2019; Whitfield et al., 2018).

Although scientific literature on digital agriculture has predominantly focused on the study of technical applications for improving agricultural practices and productivity (both reported and conceptualized), the body of literature dealing with social, economic, and institutional dimensions has also been growing in recent years (Klerkx et al., 2019). Some of these studies incorporate a critical approach to reevaluate immaculate ideas of digitalization and explore the political, ethical, and ecological dimensions of digital agriculture. Within these three areas, fundamental elements have emerged. Political aspects, for example, include the digital divide (Andrejevic, 2014; Kritikos, 2017; Rotz, Duncan, et al., 2019; Seyedsayamdost & Vanderwal, 2020), power distribution among agri-food actors (Andrejevic, 2014; Barrett & Rose, 2022; Bronson, 2018, 2019; Bronson & Knezevic, 2016; Clapp & Ruder, 2020; Kamilaris et al., 2019; Rotz, Gravelly, et al., 2019; Zheng et al., 2018), and the value systems represented by this innovation (Bronson, 2018; Bronson & Knezevic, 2016; Klerkx & Rose, 2020; Van Der Burg et al., 2019; Wolf & Wood, 1997). Ethical aspects encompass privacy and safety issues associated with the management of digital information (Hald & Kinra, 2019; Kamilaris et al., 2019; Seyedsayamdost & Vanderwal, 2020; Tang et al., 2019), forms of social participation in the innovation system (Carbonell, 2016; Thatcher et al., 2020), and the social distribution of benefits and risks of digitalization (Andrejevic, 2014; Bronson, 2019; Carbonell, 2016; Kritikos, 2017; Rotz, Duncan, et al., 2019; Van Der Burg et al., 2019). The ecological dimension is framed by issues such as the balance between efficient use of agricultural inputs and dependency relations with these inputs (Carbonell, 2016; Clapp & Ruder, 2020; Wolf & Wood, 1997), the reliability of precision data and the consequences for environmental management (Visser et al., 2021), the transformation of agricultural landscapes (Carbonell, 2016), and farmer-land relations (Rose et al., 2018, 2021), as well as the demand for natural resources in the development and operation of digital technologies (Carolan, 2017; Longo & York, 2015). In many cases, these different aspects intersect. For example, different levels of power are associated with different forms of participation, access to technologies, and the distribution of benefits. Additionally, patterns of technological inclusion-exclusion linked to certain value systems have specific environmental effects. For example, the selection of certain digital technologies can support the reconfiguration of agricultural landscapes (Legun & Burch, 2021). The amount and type of natural resources demanded also depends on the type of digital technologies involved.

Despite the important advances, the literature in these areas not only remains incipient (Carolan, 2018) and fragmented (Klerkx et al., 2019), but it is also insufficient for understanding the socio-ecological transitions of digital agriculture (Rose et al., 2021) and determining the implications of digitalization on the future of agricultural systems (Clapp & Ruder, 2020; Fraser, 2019; Klerkx & Rose, 2020; Lajoie-O'Malley et al., 2020). This knowledge gap, in turn, contributes to an institutional void, which is already characteristic of emerging technologies (Hajer, 2003). In this setting, the lack of identification of effects and future trajectories prevents the development of regulations to govern technologies (Rose & Chilvers, 2018; Veen, 2021). With a special ingredient in the case of digitalization: this process is characterized by an accelerated pace of development and launching of new technologies, which contrasts with a slow pace in the development of regulatory frameworks (OECD, 2017). It is paradoxical that although digitalization is identified as the new agricultural transition, there is no consensus on the trajectory of this transition. Clapp and Ruder (2020) express the view that environmental transitions in digital agriculture are characterized by strong opposing arguments. Proponents often emphasize the environmental benefits of more efficient agricultural input use, but critics argue that the dominant role of agri-tech corporations in this innovation system tends to favor industrial unsustainable production models highly dependent in chemical inputs, while agroecology is often overlooked. It is also uncertain how technologies applied to increase production efficiency, such as smart artifacts and autonomous machines, can impact the nature of agricultural labor and rural identities (Rose et al., 2021), including the definition of farming itself (Carolan, 2017), or how endemic processes of digitalization are currently unfolding in rural communities (Rose et al., 2018; Rose & Chilvers, 2018). In particular, a comprehensive review of social research in digital agriculture (Klerkx et al., 2019), identified policymaking, transition pathways, and geographical patterns of digitalization as poorly explored areas.

Considering this knowledge gap and the double-edged nature of technologies, the present thesis draws on a critical perspective to examine the social and environmental aspects of digital agriculture. The aim is not to stigmatize the process of digitalization or merely denounce the 'evils' of this unveiling innovation to prevent its implementation, but rather to contribute knowledge that can inform development and regulations to make this socio-technical transition work for people, production, and ecosystems. The rationale is that, since the phenomenon of digital agriculture has not yet been fully realized (Bronson, 2019), it is timely to conduct critical analyses before technological lock-in dynamics prevent changes in direction if necessary, or unintended consequences become solidified. I consider this approach necessary given that the technical opportunities of digital agriculture, together with the common hype of new technologies, can cause society to downplay vexing social and ecological questions regarding this innovation.

To advance on this exploration of social and environmental dynamics of digital agriculture, I have focused particularly on coffee, both as an agricultural system and as a value chain. This way, I tried to contribute to understand the political effects of digital agriculture from a human rights and capabilities perspective, the constellation of different technologies involved in digital agriculture, and the multiple human-land-technology interactions occurring in the territories where coffee is grown. To better understand what coffee can tell us about digitalization in the broader context of global agri-food systems, it is important to present first a few considerations about this crop.

### 1.3. Coffee as a case study

The system configured around the production and consumption of the beans of *Coffea arabica* and *Coffea canephora* keeps similarities with other globally traded agricultural products. At the same time, it is characterized by a particular set-up of political, economic, cultural, and agroecological patterns, making it an interesting case study. Coffee not only exemplifies well the manifold vulnerabilities experienced by current agricultural systems, but the history of this crop also accounts for the coevolution of our social institutions and the agrifood system, including innovations and the quest for sustainability.

With around two billion coffee cups consumed everyday (Samper & Quiñones-Ruiz, 2017), coffee is one of the most traded agricultural products worldwide (International Coffee Organization, 2019b). This product, which connects producers from the Global South with consumers in the North where the demand is concentrated (Grabs, 2020), constitutes the livelihood of more than 100 million people worldwide (Ramirez-Gomez et al., 2022), including 25 million farmers, most of whom are smallholders (Samper & Quiñones-Ruiz, 2017). Coffee growing is therefore an important economic activity in the countries where it is produced, many of them listed as Low Human Development Countries (LHDCs) (International Coffee Organization, 2019a). For these reasons, the sustainability of coffee production has been considered a major development goal (Sachs et al., 2019; Vegro & De Almeida, 2020).

The multi-billion-dollar market of coffee, estimated at about 250 billion USD (Sachs et al., 2019), is characterized by a highly dispersed rural production, that contrasts with the oligopolistic structure in the processing and retailer segments (Lerner et al., 2021). Coffee is produced in approximately 12 million coffee farms (Voora et al., 2019), 84% of them with less than 2 hectares (Panhuysen & Pierrot, 2020). Meanwhile, in the year 2019, only five companies handled half of the total coffee production (Ibid). Additionally, given high transaction costs and infrastructure gaps, farmers depend on a network of intermediaries to participate in the market (Lerner et al., 2021). The structure of the value chain, in consequence, led to an unequal participation of coffee growers in the market, and an unbalanced distribution of benefits and risks (Veen, 2021). This can be evidenced in the small fraction of the value that is captured at the producing stage,

recently calculated at only 10% (Panhuysen & Pierrot, 2020; Sachs et al., 2019). An additional consequence of this market structure is an asymmetrical transmission of price changes, where global supply increments represent profits for processors and retailers, and losses for producers (Lerner et al., 2021).

Nevertheless, within the broad structure of the global coffee market, the value chain has witnessed the emergence of alternative production and trading models that, transversely link commercial, agricultural, and institutional innovations, new consumption patterns, and sustainability goals. It is the case of the specialty coffee market (Grabs, 2017), production following sustainability standards (Dietz et al., 2020), or direct trade schemes. These models are characterized by added value, price differentiation, and more balanced power distribution (Grabs & Ponte, 2019). However, these are niche markets with entry barriers and limited demand, and for these reasons, the bulk of coffee continues to be traded in commodity markets, with commodity prices (Borrella et al., 2015; Daviron & Ponte, 2005; International Coffee Organization, 2019a).

The Coffee Value Chain (CVC) has evolved into a complex network of actors (both within and outside the agricultural sector) playing a wide range of roles. Vegro and De Almeida (2020) provide a description of this network that includes producers (family coffee farmers, medium-sized and corporate producers); cooperatives that receive, process, classify, and sell coffee to internal and external markets; rural credit institutions and insurance companies that guarantee production/income; brokers who trade coffee contracts (futures market); logistics and transport companies; roasters that transform green coffee into diverse products such as ground, roasted beans, instant coffee, and capsules; coffee shops, that through the work of their baristas sell the beverage in different forms of preparation; and consumers with different expectations regarding the experience of drinking coffee. Additional actors that can be included in this comprehensive list are wholesalers, research institutions, NGOs, development organizations, input providers, private agricultural advisors, and certifications. It is easy to understand the huge effort required to coordinate this network. In the process, a large fraction of coffee value is captured in post-production stages, and multiple inefficiencies and institutional gaps occur. In this scenario, digital technologies may play an important role in facilitating social coordination and increasing visibility of farmers in the value chain, thus, reducing transaction costs and improving farmers' participation. For example, it has been conceptualized that digital trading platforms and traceability systems can facilitate farmers' access to markets, or the monitoring of production standards, attributes of coffee, and commercial practices (International Coffee Organization, 2020; Sachs et al., 2019), in theory, allowing farmers to capture more value and adding more transparency to the value chain.

In agroecological terms, a large proportion of coffee is grown in mountainous areas and on small family farms. This segment it is not suitable for mechanization, and commonly it is grown, harvested, and initially processed without using modern machines (Vegro & De Almeida, 2020). These characteristics present an

interesting case to explore how digitalization evolves in this scenario with special challenges for the operation of technologies such as smart tractors, or harvesting robots, and how digital technologies are appropriated by smallholder producers. For instance, the agricultural setting of coffee production could promote the use of disembodied digital technologies or the development of machines with the ability to operate in medium and small-scale, mosaic landscapes, and steep terrain. Another proportion of coffee is produced in large-scale industrialized plantations, particularly in some ecoregions of Brazil (De Almeida & Zylbersztajn, 2017). Coffee, therefore, offers an opportunity to compare the process of digitalization in different agricultural settings.

Innovations have accompanied coffee throughout its history. Probably its global scale, market size, public-private investments, complex social network, and relevance for rural development, make this value chain a system prone to different forms of innovation. Some remarkable examples are its pioneering role in the implementation of sustainability standards such as organic production and Fair Trade (Barham et al., 2011), the development of genetic traits (there exist more than 100 different varieties of coffee), and the multitude of methods for processing and consuming it that have created large industries around them. Digitalization probably will not be the exception to this innovation impetus. As an indication, Sott et al. (2020) portrayed a very dynamic scenario of research in the digitalization of the CVC in the academic sector, with emerging technologies such as machine learning, and the Internet of Things (IoT) appearing in the literature as promising innovations. However, it is necessary to assess how many of these applications can be applied effectively in the industry, how, and with what consequences.

As mentioned before, the CVC is characterized by conditions of social imbalance and institutional gaps. These conditions, consequently, have produced a systemic problem of poverty and vulnerability among coffee growers (Grabs, 2017; Panhuysen & Pierrot, 2020; Sachs et al., 2019; Voora et al., 2019), given that they are subjected to low and volatile farmgate prices (Civera et al., 2019; International Coffee Organization, 2020; Samper and Quiñones-Ruiz, 2017; Specialty Coffee Association, 2019). This is not the only challenge that coffee faces for its sustainability; there is a group of other relevant social and ecological issues that not only affect the CVC but are shared by many other agricultural chains. For example, climate change and its effects on temperatures, rain distribution, and patterns of pests and diseases, has been described as one of the most pervasive challenges for coffee production (Läderach et al., 2017; Sachs et al., 2019; Sott et al., 2020; Specialty Coffee Association, 2019). According to Bunn et al. (2015), by 2050, climate change alone potentially will reduce 50% of the area suitable for coffee production. Meanwhile, coffee is also responsible for negative environmental impacts, some of which have consequences for the emissions of greenhouse gases. It is the case of deforestation to increase the cultivated area or the overuse of synthetic fertilizers (International Coffee Organization, 2020; Sachs et al., 2019). Additional challenges for the sustainability of

the CVC that have been reported in the literature are a lack of transparency and information asymmetry among actors (Gardner et al., 2019; Samper & Quiñones-Ruiz, 2017), impacts on production by pests and diseases (Vegro & De Almeida, 2020), and pollution caused by pesticides, fertilizers, and organic solid waste (Perfecto & Vandermeer, 2015).

Conceptualizations of digital agriculture see these technologies as an opportunity to address several of these challenges. For example, digital tools can facilitate access to information about agricultural practices (including agroecology or climate-smart agriculture), market trends, weather patterns, agricultural inputs, agricultural and financial services, and innovations (International Coffee Organization, 2020; Sachs et al., 2019). Access to this type of information can, in turn, help farmers improve decision-making on the farm, leading to efficiency and productivity gains. It can also support the implementation of sustainability practices, reducing environmental impacts, enhance adaptation to climate change, improve market decisions and reduce knowledge asymmetries. Digitalization can connect farmers with input and service providers and promote access to innovations. Additionally, as previously discussed, digital trading platforms (e-commerce) and traceability systems may enhance the visibility, participation, and credibility of farmers, favoring the capture of value in the production stage, reducing economic vulnerability. These opportunities remain untested, and potential adverse consequences can also be expected. Therefore, it is important to closely explore the way digitalization is evolving in the CVC. It is precisely a need for this kind of understanding what motivated the critical approach of this thesis and the objectives that have been set.

#### **1.4. Objectives and research questions**

As mentioned above, digital technologies have the potential to produce both positive and negative effects at societal and ecological levels. In fact, different sets of trade-offs can occur simultaneously, resulting in improvements of some conditions, and worsening of others. Also has been expressed why coffee presents a case of interest given its socio-economic and agroecological context, along with the different sustainability challenges that it faces. Under these considerations, this thesis proposes the following three general research objectives: 1) Examine how digital agriculture affects the lives of farmers from a political perspective; 2) Identify sustainability pathways that digital agriculture is promoting for the CVC; 3) Understand the appropriation of digital technologies by coffee growers. The aim is to contribute to answer relevant research questions that can hopefully help understand the role of digitalization in the sustainability of agriculture, understanding agriculture as a configuration of technical, social, and ecological relationships. The digitalization of agriculture is an emergent innovation; however, it is rapidly occupying spaces in agriculture, not only through new applications, but also in innovation narratives, development discourses, and conceptualizations about the relationship between society and technology. Institutional arrangements to

regulate this process are required, especially those using a responsible approach (Bronson, 2018; C. Eastwood et al., 2019). For this, it is necessary to increase the theoretical and empirical knowledge about digitalization using a systems and critical approach. This thesis starts framing the broad political scenario of digitalization in agriculture from a human rights and capabilities perspective, integrating the diverse set of technologies and agricultural systems engaged in digital agriculture. After that frame, this thesis moves towards the more specific case of digitalization in the CVC, maintaining a global perspective, and a multi-technology approach. Subsequently, the issue of appropriation of digital technologies in the particular context of the Colombian coffee system is explored. Following this structure allows the analysis to be placed across multiple scales, going from the macro (a global scope, and broad set of digital technologies) to the micro (a local case study with specific technologies), and at the same time, facilitating the analysis of particular social dynamics taking place at each scale.

#### **1.4.1. Impact of digital agriculture in the life of farmers**

Previous reviews of digital agriculture from the social sciences have made relevant contributions to assembling the multi-faceted social dimensions of digital agriculture (e.g. Klerkx et al., 2019; Rotz et al., 2019a; Van Der Burg et al., 2019; Wolfert et al., 2017). However, these reviews lack formal conceptual frameworks that help to understand the concrete consequences of digital agriculture in the lives of farmers. Particularly, their political position in the world represented by their agency and sovereignty has been explored with a lack of conceptualization, leaving previous political analysis incomplete, and the consequences over these two conditions unclear. It is of special interest to develop a such a conceptual and empirical analysis with inclusion of areas beyond big data, and smart farming (real-time farm operations based on agricultural big data), the most pervasive topics explored so far in the literature. Consequently, the first objective of this thesis is to examine different positive and negative impacts of digital agriculture in the life of farmers from a political perspective. This is achieved through describing how digital agriculture particularly affects farmers' sovereignty and agency. This description is based on a formal conceptualization of these two conditions. To address this first objective, the next research questions have been framed in the first paper (chapter 2).

- a) How sovereignty and agency concepts can be framed in the context of digital agriculture?
- b) How is sovereignty and agency of farmers affected positively and negatively by digital agriculture?
- b) What specific governance mechanisms of digital agriculture produce these effects?

### **1.4.2. Digitalization of the coffee value chain and pathways towards sustainability**

The application of digital technologies in the CVC has been explored in the literature from a technical perspective. Different technologies have been explored in experimental settings (e.g. Chemura et al., 2017; Escola et al., 2020; Lasso et al., 2018; Velásquez et al., 2020), or through research applied to the industry (Miatton & Amado, 2020; Sachs et al., 2019; Schwartzman & Parikh, 2007). However, social and ecological dimensions of digitalization in the CVC have been particularly neglected in research. Consequently, the societal transition proposed by the process of digitalization in the CVC has not been examined, and the consequences of this transition for the sustainability of the value chain remain uncertain. The second objective of the thesis is to identify sustainability pathways that digital agriculture is promoting for the CVC, considering the broad spectrum of different technologies involved, and its interaction with the social and ecological system of coffee production. To address this objective, the next research questions have been framed in the second paper (chapter 3).

- a) What are the technical characteristics of digital technologies and how have they been applied to address the sustainability challenges of the CVC?
- b) What socio-technical pathways are being promoted by such technologies and what social and environmental consequences do they represent?

### **1.4.3. Appropriation of digital technologies by Colombian coffee farmers**

The particular perspectives of rural communities regarding digitalization, and the distinctive forms in which these communities are currently interacting with digital technologies in their own terms, have been poorly explored in the literature. This despite the fact that a gap between the perspective of developers and proponents of digital technologies and the reality of farming communities has been systematically reported (Contreras-Medina et al., 2020; C. Eastwood et al., 2019; Heeks, 2002; Prost et al., 2012; Rose et al., 2018). Additionally, the inclusion of farmers' perspectives has been widely recognized as a prerequisite for responsible innovation (Bouroncle et al., 2019; Bronson, 2018; Duncombe, 2016; Rose & Chilvers, 2018, 2018), and for the effective uptake of technologies (Howland et al., 2015; Pannell et al., 2006). It has been addressed that relevant future research should provide more clarity regarding the societal role of farms, and imaginings of actors involved with digital agriculture in setting the different goals that digitalization can serve (Van Der Burg et al., 2019). Using the case of the coffee farming system in Colombia, this thesis proposes to explore perceptions, attitudes, and current use of digital technologies by local communities. The third objective of this thesis is, therefore, to understand how two different communities of coffee growers in Colombia interact with digital technologies, through the use and the position assigned to these

technologies in their imaginaries. To address this objective, the next research questions have been framed in the third paper (chapter 4).

- a) What are the elements that configure a valuable life for the two communities of Colombian coffee growers?
- b) How do these communities use digital technologies to support the accomplishment of this life?

## **1.5. Conceptual framework**

### **1.5.1. Socio-technical systems**

The social and ecological effects of digitalization, and the pathways towards sustainability that digital technologies facilitate and allow for agricultural systems cannot be examined without understanding that technologies encompass technical elements as well as social, physical, and cyber (in the case of digital technologies) dimensions. These elements are inextricably bound together in a way that, through their interaction, shape each other. This idea has been discussed through the concepts of ‘socio-technical systems’ (Bijker, 1999; Hughes, 1987), the ‘social determination of technologies’ (Winner, 1980), or ‘cyber-physical-social systems’ (Lioutas et al., 2019). These different concepts assert that technologies are not only socially constructed but through their use, they also produce and reproduce particular social and ecological contexts. To complement this, Guston (2014) presented the idea that innovation is in the same proportion technical processes, products, and people. According to Rijswijk et al. (2021), digital agriculture embodies a hybrid system composed of interacting entities from social, technical, biological, and physical domains.

The idea that technologies are socially constructed presents different conceptual implications. Firstly, it proposes that technology is physically constructed by its designers, but socially constructed through the meaning assigned by the users and the way it is operated (Orlikowski, 1992a). Secondly, it frames the idea that technology is a product of the social context where it is embedded (Zuboff, 1988) and that this context, in turn, determines the way technologies are used and the societal consequences derived from this use (Hellström, 2003). Thirdly, technologies produce certain social and ecological contexts through their use and regulation. These are promoted and allowed by the affordances that they offer to users, together with the influence of design decisions that create compatibilities and incompatibilities with existing or projected social systems, casting technological imperatives (Winner, 1980).

In a seminal paper about the role of technologies in organizations, Orlikowski (1992) described how the technical attributes of a technology (which can be more or less fixed) are endowed with social meaning

through the context of use. Therefore, this meaning can vary across different social settings and can be transformed in different ways by users. This idea has also been expressed by Pirnejad and Bal (2012) when they mention that the meaning of a technical artifact does not lie entirely in the technical design, but it is shaped by social interaction. Sterne (2003) describes that technologies are co-created by their makers and users through use, which can change over time and be different for different social groups. Incorporating these notions forms the basis for the deliberate use of the term ‘appropriation’ throughout this thesis, instead of the most common (but mostly inaccurate) term of ‘adoption’ when referring to the uptake of technologies by farmers. While the latter expresses more of a process of passively taking technologies as they are designed and produced (which is rarely the case), the former recognizes the active process of selection, adaptation, and application of technologies in which farmers are involved. In the case of digital agriculture, the role of farmers in the process of co-creation acquires a particular character, as they, using digital technologies on the farm, become simultaneously users, producers, and transformers of agricultural digital data (Lioutas et al., 2019).

Technologies are not created and deployed in a vacuum; they are embedded in a social context that shapes the way technologies are designed, used, and regulated. Despite the common belief that technologies are the product of objective work grounded in purely technical mandates, technologies inherently embody values (Bronson, 2018). These values, in turn, are the product of historical processes and situated knowledge. In this regard, it has been framed that the work of designers is not free from imprinting (deliberately or inadvertently) their values in technologies (Friedman & Kahn, 2002). In turn, these values determine the rationalization of a problem and the way it is conceived to be solved through technology. Alongside values, technologies also represent particular forms of power and authority (Winner, 1980; Zheng & Yu, 2016). The frames of action endorsed and allowed by technologies influence people’s behavior. This situation, together with the forms of regulating technologies, originates specific forms of agency unevenly distributed among social actors. Technical attributes are products of design decisions, made by social actors who hold particular knowledge, beliefs, and value systems, and who follow particular norms. The process thereby allocates special forms of authority to these actors (who can be multi-faceted and mixed) because they influence the options that people have for solving problems through technology. At the same time, the process of social appropriation allocates authority to users as their decisions transform technologies, but also the world through the use of technologies.

Digital technologies can transform farms physically through the use given by farmers. This transformation presents ecological consequences, such as landscape transformation, changes in the flows of matter and energy, and alterations to the conditions for plants and animals. Literature reports transformations of the social context as well. These transformations can be examined in a broader social context but can also be

assessed at the farm and the personal spheres. According to Winner (1980), technologies are inherently political, as the implementation of particular technical systems unavoidably casts certain political structures through the social relationships they create. These structures can be of different nature (e.g. centralized or decentralized, egalitarian or inegalitarian, repressive or liberating). In the case of digital agriculture, there are contrasting views regarding the types of social relationships that can emerge. Some authors argue that digitalization democratizes access to information and control over technologies (Aker, 2011; Baumüller, 2018; FAO, 2013; Kos & Kloppenburg, 2019; OECD, 2017; G. Prause & Boevsky, 2019). Others argue that it reinforces the dominance of already powerful actors such as agri-tech corporations or industrialized large-scale farmers (Bronson, 2018; Clapp & Ruder, 2020; Hackfort, 2023; Klerkx & Rose, 2020; Lioutas et al., 2019). Changes in labor, both qualitative and quantitative, linked to digitalization may transform the social context at regional and local scales, creating opportunities for some rural workers, while excluding others (Rose et al., 2018; Rotz, Gravely, et al., 2019). In the personal sphere, it has been described that the mediation of digital technologies in farm work may “re-script” the way farmers interact with the land (Rose et al., 2018) or reframe the definitions (socially constructed within and beyond farms) of ‘good farming’, ‘good farmers’, and ‘good farms’, influencing farmers’ identities (Carolan, 2018; C. Eastwood et al., 2019; Van Der Burg et al., 2019).

Conceptualizing technologies as a socio-technical system moves the analysis of digital agriculture beyond the farm and locates it within the broader social context where technologies are embedded, including what Klerkx et al. (2019) have described as the wider community of users and co-producers, and the institutional setting that regulates the innovation system. Additionally, rationalizing the idea that technologies and society are mutually shaped necessarily brings attention to the responsibility of innovations in the process of creating social realities, and shaping political structures and ecological relationships; a process that, I described already, is underpinned by values and subjective norms. Precisely, these premises are part of the fundamentals of a theoretical and practical approach engaged in critically assessing the futures proposed through technological transformations and the values underlying this process. It also proposes ways to rethink these futures with inclusiveness and reflexivity; this approach is known as responsible innovation.

### **1.5.2. Responsible innovation**

Assuming that the process of innovation is not neutral, but underpinned by values and social norms, presents different consequences for assessing the role of technologies in society, and the way research and practice of innovation can be approached for the good of society and the environment. One of these consequences is the rationalization that innovation supports certain socio-technical transitions while excluding others (Pigford et al., 2018; Schlaile et al., 2017; Winner, 1980). Accordingly, these transitions foster particular

power structures and social realities at the expense of others (Winner, 1980). It also sets the need for examining the group of societal values and norms that are incorporated in the process, and what actors are represented by them, especially if innovations are intended to work towards the interests and concerns of wider segments of society (Bronson & Knezevic, 2016; Hellström, 2003; Stilgoe et al., 2013; Von Schomberg, 2012). In other words, to understand the role of technologies in society, social research regarding technologies should make important questions such as, what technologies ought to do and for whom (Bronson, 2019), and who is driving the process (Crossley, 2018, in Rose and Chilvers, 2018). These elements of values, power structures, dynamics of technical and societal inclusion-exclusion, inherent to technologies, and their consequences for human development, ineluctably link research and practice of innovation with ethical questions regarding representativeness, participation, fairness, freedom, or integrity.

The theoretical framework, defined as ‘responsible innovation’ (RI), has been developed to address aspects related to social and ethical dimensions in research and design of new technologies. Its aim is to anticipate and provide alternatives to potential harms caused by these technologies, as well as to incorporate broad spectrums of societal concerns (Stilgoe et al., 2013). RI involves reflecting on the plausible futures that technologies can create, and how the innovation process can be driven towards sustainability. This perspective is grounded in the idea that the future is not predetermined, but continuously shaped by the thoughts and actions of the present (Lajoie-O’Malley et al., 2020). Accordingly, RI has been originally defined as “a collective commitment of care for the future through responsive stewardship of science and innovation in the present” (Owen et al., 2013, p. 36).

In the case of digital agriculture, applying a RI approach means putting into practice techniques to anticipate the impacts of this innovation at different scales, such as the farm, the landscape, food chains, and the effects on rural communities (Rose & Chilvers, 2018). Proponents of RI in digital agriculture call for applying the principle of reflexivity to assess beneficial trajectories of agrifood systems (C. Eastwood et al., 2019) and to integrate the specificities of digital agriculture to create contextualized RI frameworks (Rose & Chilvers, 2018). A constituent element of RI is the integration of broad sets of social and environmental concerns into the research and practice of technological innovation. For this reason, it calls for inclusionary approaches and responsive capacity (Stilgoe et al., 2013). In the exercise of RI, there should be space for multiple voices; stakeholders in the projected future that innovations are contributing to build. In the case of digital agriculture, an inclusionary process requires the effective participation of actors such as farmers and other land managers, landowners, cooperatives, advisors, retailers, consumers, technology companies, NGOs, and policymakers (Klerkx et al., 2019). Additionally, RI demands the capacity to change and adapt innovation processes to respond to newly incorporated values, additional socio-environmental concerns, and changing circumstances (Stilgoe et al., 2013), and to be responsive to the emerging consequences of innovation, in

many cases unintended (Klerkx et al., 2019). In a very important way, responsiveness also involves the recognition of the possibility that multiple beneficial trajectories can coexist (C. Eastwood et al., 2019).

Because RI involves the exercise of imagining desired futures, it calls for an open perspective on the multiplicity of ideas about what a desired future looks like, as well as the diverse pathways to get there. Preconceived notions of development play a crucial role in shaping this envisioned future. Development discourses inevitably influence public policy and the direction of social change following specific institutional logics (Hayes & Westrup, 2012). In contrast to a single notion of development and beyond orthodox ideas that equate development with economic growth, technification, or industrialization, RI integrates the idea that multiple ideas of development coexist in the world. These ideas can be contrasting among social actors and encompass a wide range of values. One conceptual framework that proves useful in articulating this notion of multiple development possibilities is the capabilities approach (CA) developed by Amartya Sen, and his concept of development as freedom (Sen, 1999).

### **1.5.3. Capabilities approach**

The RI framework calls for inclusivity in the innovation process. Because ideas of development drive the visions of a desirable future and the proposed socio-technical pathways to build it, it is necessary to build notions of development that are inclusive with multiple worldviews. To do this, the CA elaborated by Amartya Sen (1999) works as an appropriate conceptual framework, as it challenges more orthodox ideas of development that are made up of a singular goal (predominantly economic and industrial growth), framed with a top-down approach, and where local communities are perceived as passive recipients of help. In contrast, CA defines development as the freedom people have to live the lives they value (Sen, 1999). Development, therefore, can take different forms and be represented by multiple values. Development under this approach encompasses all the diversity of possible personal and collective goals, and the multiple trajectories that can lead to achieving these goals. In other words, multiple development pathways coexist and should be recognized and respected (A. Jiménez & Zheng, 2017). To integrate the principle of inclusiveness, in this thesis I followed CA to frame the idea of development when assessing the role of digital technologies for rural development. This framework was also used to establish lines of comparison with the dominant narratives and practices in digital agriculture, aiming to identify the negotiations and tensions that occur when different ideas of development interface in the digital agriculture sphere.

Fundamental to Sen's idea of development are the concepts of "functionings" and "capabilities". While functionings are the "various things a person may value doing or being" (Sen, 1999, p. 75), capabilities are "the alternative combinations of functionings that are feasible for her to achieve" (Sen, 1999, p. 75). In other words, "capabilities" reflect people's real opportunities (Gasper, 2007). Consequently, the aim of

development should focus on the expansion of people's capabilities (Kleine et al., 2012). The outcome of development in CA should be evaluated in terms of well-being, choices, and the agency of individuals to effectively use their available opportunities. In this way, CA offers a more holistic view of development processes (Zheng et al., 2018). Additionally, in Sen's propositions, development is not only the expansion of the freedoms that people can access, but also the removal of major sources of unfreedom, which include poverty, tyranny, or social exclusion and neglect (Sen, 1999).

In CA, attention is focused on the capacity of individuals and collectives to transform resources into assets, and the conditions that constrain or enable that capacity (Sen, 1999). Following this argument, Carolan (2018) proposes that there is no intrinsic value in goods and services (which can include technologies), and rights. The value of these resources is determined by the possibility of using them to produce outcomes that people deem valuable (Ibid). In these terms, technologies can be assessed as drivers of people's freedom to live the lives they value (Kleine et al., 2012). Agency in this context, is usually associated with people's possibility to use technology to improve their quality of life (Zheng, 2009), supporting the idea that access to technologies alone does not improve people's well-being. What transforms technologies into assets is the possibility of using them effectively to achieve a valuable life. What this valuable life represents is highly contextual and diverse, as is the role of technologies in achieving it. Technologies can also become sources of unfreedom, for example, when the possibility of using them effectively is not present, or when people are coerced to use technologies that do not reflect the lives they value (Kleine et al., 2012).

By applying the CA in the analysis of innovation processes, the needs and aspirations of those actors affected (positively or negatively) by innovations are considered. It is recognized that innovation processes and their outcomes are multifaceted, not necessarily leading to economic growth, but also presenting the possibility of producing equally important opportunities for human development, such as identity, social capital or personal and collective goals (A. Jiménez & Zheng, 2018). Following these ideas means considering that the innovation process only contributes to development if people involved perceive value in the innovation and in the outcome. In sum, if people perceive that their capabilities have been expanded and respected throughout the process of innovation.

#### **1.5.4. Integrating socio-technical systems, responsible innovation, and capabilities**

Based on the concepts of socio-technical systems, RI, and the CA, I propose an integrated model that links, in hierarchical order, the different facets of these concepts. These concepts orient the conceptual approach used in this thesis to explore the socio-technical-physical interactions of digital agriculture (Figure 1). The basic idea, where the other concepts are embedded, is that innovations (digital agriculture in the case of this thesis) are *socio-technical systems*. Society and technical systems continuously shape each other through

dynamic interactions. Structural social systems and situated cultural values set the context from which innovations emerge, defining the promoted socio-technical projects and the ones that are not, and defining the ways in which technologies are socially constructed. Technologies, on the other hand, shape society, influencing human behavior and producing or hindering particular social, political, and economic systems. In this linkage, technologies are prone to producing different social impacts, many of them unforeseeable, unintended, and unwanted, highlighting the relevance of applying the framework of *RI*, the second order concept. To acknowledge and be accountable for these impacts, *RI* proposes the application of the principles of anticipation, reflexivity, inclusion, and responsiveness in research and the practice of innovation. A component of this framework is the idea that multiple desirable futures and socio-technical pathways to build those futures can co-exist, and should be recognized, and respected. As the third order concept, *CA* appears as an appropriate framework to integrate this notion of multiplicity present in *RI*, given that it is a form of recognizing the existence of multiple ideas of development. *CA* supports the notion that technologies have different roles in achieving the diverse spectrum of development goals that people and collectives can hold. Additionally, *CA* also incorporates the idea that technologies simultaneously present the possibility of being enhancers or hinderers of people's agency, opening the opportunity to explore the multiple and contrasting trajectories that digital agriculture can facilitate for agricultural systems.

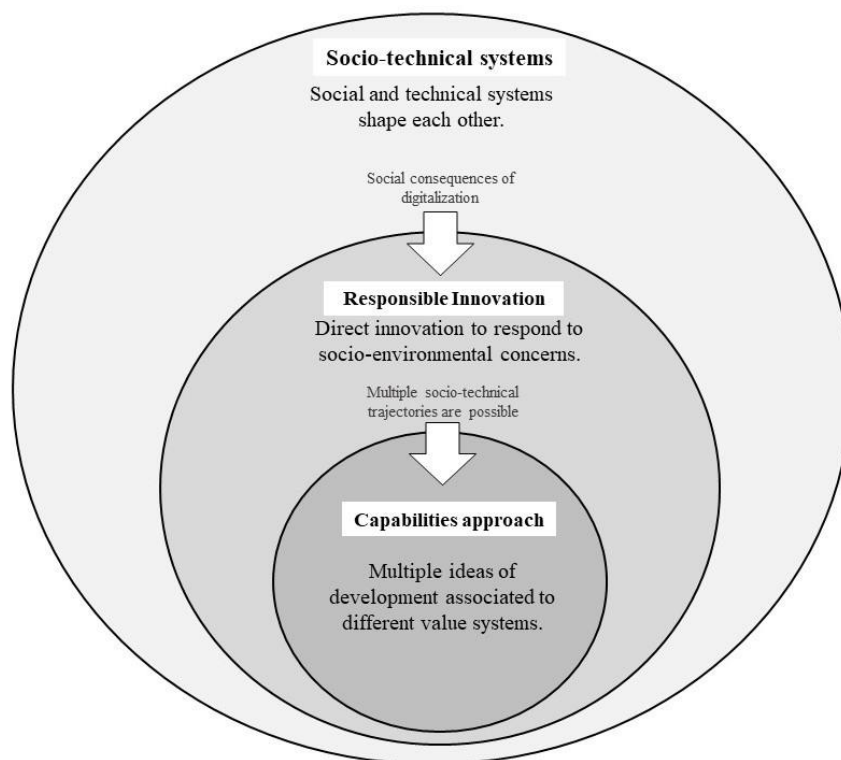


Figure 1 Conceptual framework. Integrated concepts of socio-technical systems, *RI*, and *CA*

## **1.6. Methodological approach**

The present thesis is framed within the field of social sciences. The analysis focuses on studying the socio-technical process defined as digital agriculture, and its cultural, political, and environmental consequences. Therefore, it can be inferred that this study is focused on human action and social institutions developed within a specific technological ‘environment’. The analysis is built upon an epistemological body derived from theoretical and conceptual frameworks from the social sciences (e.g. socio-technical systems, RI, CA). The phenomenon I am trying to explore throughout this thesis is interpretive in nature. The critical perspective adopted in this work calls for making visible dynamics (e.g. power structures, development trajectories, knowledge and value systems) that, first, are not represented by material elements that can be counted and measured; second, they are not directly evident in nature but rather expressed in social relations that require processes of interpretation. This systematic interpretation is conducted on detailed information existing in the form of text and conversations. For this reason, in answering the research questions, I followed a qualitative approach, applying qualitative methods of data collection, analysis, and reporting.

This thesis loosely follows the principles of grounded theory. Or rather, grounded theory is understood here as an open and flexible methodology. Grounded theory can be considered a systematic approach that allows for various forms and levels of application (ranging from the most categorical to most partial forms). In the process of applying grounded theory, I integrated important considerations that contributed to building a nuanced understanding and application of this approach. Grounded theory has been defined as a set of systematic “guidelines for collecting and analyzing qualitative data to construct theories from the data themselves” (Charmaz, 2014, p. 1). The process begins with inductive data, looking at data without preconceptions (Charmaz et al., 2017). The iterative process of moving between data and analysis is what provides explanatory capacity (Charmaz, 2014). For that reason, in grounded theory, data precedes theory; therefore, it is expressed that theory is “grounded” on data (Charmaz et al., 2017). Charmaz herself (2000, 2014), however, proposes a constructivist version of grounded theory, where the inevitability of preconceptions is acknowledged instead of denied. Following these ideas, I recognize that my approach to the data did not occur in *tabula rasa*. At the moment of collecting the data, I already had built basic notions about the phenomenon of digital agriculture, the technical possibilities that it presents, and the existence of multiple societal and environmental positive and negative consequences derived from its implementation. Rather, the conceptual models used to analyze the data, and the pathways that my own analysis could identify and describe, were not present in this study before engaging with the data. It even required an iterative process of analysis before coming to the categories and themes presented in the different chapters of this thesis.

To keep the researcher open and free of preconceived ideas, the foundational form of grounded theory calls for delaying the literature review until the late stages of the research, even after completing most of the analysis (Strauss, 1987). Thornberg (2012), however, described the assumption that the researcher can be free of preconceptions as “naive empiricism,” and suggested that literature serves as an 'inoculator' of preconceptions. He suggested that overcoming these notions creates what can be defined as “informed grounded theory.” Before collecting the data, I familiarized myself with relevant literature about digital agriculture, industry 4.0, and technology studies. As a result, the kind of grounded theory that I applied in this thesis is an informed grounded theory. In fact, the first paper is an exploratory literature review. I do not consider this condition a setback, on the contrary, it resonates with the ideas of Charmaz et al. (2017) regarding engaging with literature in grounded theory. According to them, familiarity with relevant literature offers the possibility of enhancing sensitivity to nuances in data, generating concepts and the comparisons with previous concepts, raising critical questions, and identifying areas for conceptual development. Rather, when engaging with literature, I applied the following principles presented by Charmaz et al. (2017): (a) theoretical agnosticism to treat extant theories as provisional and disputable; (b) theoretical pluralism to maintain an open mind and integrate multiple perspectives; (c) theoretical sampling<sup>1</sup> of literature to be more sensitive to data and the emerging theory and its concepts; and (d) theoretical playfulness to explore preexisting theoretical concepts and ideas in new, innovative, creative, and unorthodox ways. The application of this approach resulted in the novel concept of techno-governance developed in Chapter 2, the conceptual assemblage of socio-technical systems and technical characteristics of artifacts presented in Chapter 3, and the application of the CA to the concept of social construction of technology presented in Chapter 4.

In grounded theory, the development of case studies, and the collection of data through interviews and analysis of texts are common practices (Denzin & Lincoln, 2018). I also made use of these elements in this thesis. On the one hand, I selected coffee as a case of interest for the exploration of socio-environmental implications of digital technologies in agriculture. On the other hand, the main sources of information in the papers were semi-structured interviews, and secondary information. A process guided by a theoretical sampling of literature (Table 1). It has been argued that by focusing the study on a single phenomenon, individual, community, or institution, the case study approach allows to unveil latent interactions, and to capture a more nuanced understanding that other research approaches might allow (Lune & Berg, 2017). Semi-structured interviews, on the other hand, have a central place in the methodology of this thesis. Qualitative semi-structured interviewing fits grounded theory particularly well given that both present a

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<sup>1</sup> A form of selecting the literature in which the selection is guided by different areas of interest and knowledge gaps that appear as the research progresses. Theoretical sampling is aligned with the principles of grounded theory as it is an ever emergent and iterative process of engagement with literature.

good balance between openness, flexibility, emergence, and structure (Charmaz, 2014). Additionally, it has been argued that through intensive qualitative interviewing, researchers can reach levels of understanding that would otherwise remain inaccessible, such as people’s subjective experiences and attitudes (Peräkylä, 2005), or comprehensive narrations of complex processes, such as the development of a particular technology. In paper 2 (Chapter 3), the sample was composed by developers of digital technologies for the coffee sector (N=15). In paper 3 (Chapter 4), the sample was composed by households of two selected coffee growing communities in Colombia (N=73). One of these communities located in the northern region in the Caribbean, and the other in the central Andes. Field notes were also taken during the field work with these communities.

*Table 1 Methods for data collection and analysis applied in this thesis*

<b>Paper</b>	<b>Literature review</b>	<b>Secondary data</b>	<b>Primary data</b>	<b>Analysis</b>
Techno-barons or networked freemen	Theoretical sampling	-	-	Inductive coding – from text to categories
Digitalization, sustainability, and coffee	-	Theoretical sampling <i>Source:</i> websites, news, reports, apps, papers, conference presentations, podcasts	Purposive sampling <i>Source:</i> semi-structured interviews	Inductive coding – from text and conversation to categories
How do coffee farmers engage with digital technologies?	-	-	Purposive sampling <i>Source:</i> semi-structured interviews	Inductive coding – from conversation to themes

The semi-structured form of interviews applied in this thesis provided a conversational structure, presenting the possibility for interviewees to express their own perspectives with their own words. A broad script guided the interviews across general topics of interest. However, the possibility of exploring new areas was always present, as well as going deeper into particular aspects or addressing the topics in the natural order that they appear in the conversation. The latter facilitated the emergence of narratives that interconnected the different issues in a logical way. In this regard, the interview process, as conducted in this thesis, confirmed what Brinkmann and Kvale (2015) expressed about semi-structured interviews and the possibility they bring to the interviewee to guide the interview towards the issues that he or she deems important. According to the authors, qualitative semi-structured interviews aim to obtain descriptions of the interviewee's life. These descriptions, in turn, are used to interpret the meaning of the described phenomena. This possibility was explored to acquire a deep understanding of different processes of development of digital tools from the developer's perspective and the values and perceptions that determine local forms of engagement with digital technologies.

Following a grounded theory approach, the method applied in this thesis for analyzing the data was content analysis in the form of inductive categorization and coding. This process was not applied only to the interviews, but also to the literature and the secondary data. Content analysis has been described as a systematic and detailed examination of a particular information body in order to identify patterns, themes, and meanings (Neuendorf, 2017). According to Lune and Berg (2017), content analysis is typically conducted on forms of human communication, including permutations of written documents. However, it also includes conversations that have been translated into text for analysis. I conducted content analysis to the consulted literature and secondary data to create categories for interpretation and elaboration of conceptual frameworks. In the case of semi-structured interviews, I conducted content analysis to transcripts of the interviews to infer themes. This is a deeper process of analysis than categorization, as the aim, more than organization and description of the data, is to extract meaning from it. Coding is an important component of content analysis. Building grounded theory requires early engagement with data, separating it, sorting it, and synthesizing it through qualitative coding (Charmaz, 2014). The process of coding refers to assigning terms to segments of data to summarize, categorize, and account for these segments (Charmaz et al., 2017). It is also about asking what is happening in small segments of data and linking them with theoretical categories (Ibid). It is important to clarify that categories, such as the ones defined in this thesis for the literature and secondary sources, are groups of codes similar to each other. Meanwhile, themes (the ones that emerged in the interviews) tend to be more abstract and use higher level concepts. Consistent with a grounded theory approach, the type of coding I conducted in this thesis was inductive. Inductive coding has been described as the identification of codes and themes while scrutinizing the data, instead of approaching the data with pre-defined codes, therefore emphasizing emergence (Charmaz, 2014). Inductive

coding involves two forms of coding. Initial coding, more generic, embryonic, close to the data, and remaining open to exploring new explanations and descriptions; and focused coding, which is more directed, selective, and conceptual (Charmaz et al., 2017). During focused coding, researchers examine the codes and decide which ones better capture the meaning in the data, provide conceptual definitions to the findings and establish relationships between codes (Charmaz, 2014). This kind of iterative inductive coding derived into the categories of *governing through technology*, *governing the technology*, *agency enhancement*, *agency hindrance* presented in paper 1; *knowledge and value systems*, *power structures*, *effective use*, *functionality*, *technologies involved*, *operation rules*, *information flow* presented in paper 2; and the themes of *relational way of farming*, *(dis)connected machines*, and *nurtured families and communities*, presented in paper 3.

## 1.7. Outline of the thesis

In correspondence with the objectives and research questions of the thesis, three different papers are presented in the following chapters. Through these papers, varying socio-technical aspects of digital agriculture have been explored, such as techno-governance systems and their consequences to human rights and capabilities, the consequences of different groups of digital technologies for sustainability of agrifood systems, and local material and symbolic interactions with digital technologies in a rural context. These explorations, in turn, offer a comprehensive view of the multiple dimensions that make digital agriculture a system with multiple future pathways and socio-environmental consequences. For this exploratory study, coffee, as a crop, a cultural system, and a value chain, has been selected as a case study.

To set the broad scenario, the **first paper** (Chapter 2) introduces an emancipatory perspective of global political dynamics in digital agriculture that occur through different modes of techno-governance. The paper poses the relevant question of how these political dynamics specially affect farmer's sovereignty and agency (explicitly conceptualized in this paper), and the consequences for their development and political position in a context of systemic power asymmetries. The paper also analyzes different examples where an emancipatory epistemology has been applied to cast a democratic facet of digital agriculture and concludes with recommendations to reinforce this positive trajectory.

The **second paper** (Chapter 3) takes a global approach to the process of digitalization, this time with a focus on the CVC. The paper presents a technical and socio-environmental analysis of the current scenario of digitalization in the CVC, and the possible future trajectories. The discussion is centered around 20 different digital tools for the production stage (from farm to cooperatives). The paper explores the different pathways towards sustainability (social, economic, environmental) that this group of tools is proposing for the CVC, and what the challenges are for a meaningful digital transformation of the sector.

The **third paper** (Chapter 4) offers a local perspective of the process of digitalization. This paper explores the way two communities of Colombian coffee growers interact with digital technologies in material and symbolic ways (the position of these technologies in their imaginaries) in their everyday practices. This exploration is guided by the CA. For this reason, it is centered around the elements that make life valuable for these communities and the way digital technologies such as mobile phones, smartphones, tablets, computers, digital social networks, robots, and drones are used (or not) to follow this life. By comparing the underlying values of this local process with broader narratives of digital agriculture, the paper offers an opportunity to highlight the negotiations and tensions that occur between contrasting visions of farming, digitalization, and a desirable future. The paper concludes by pointing out the relevance of integrating a sense of multiplicity when studying the digital and the rural.

Following these three papers, a discussion section elaborates on the overall contribution of the thesis to the literature guided by the concepts of socio-technical systems, RI, and CA. The thesis ends with some concluding remarks, limitations, and suggestions for future research.

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## 2. Techno-barons or networked freemen? Digital agriculture through an emancipatory lens

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### Abstract

Digital agriculture presents profound consequences in the lives of farmers. Not only their livelihoods and agricultural practices, but their very same modes of life, rights, and capabilities, are impacted by these technologies. Sovereignty and agency are two connected concepts commonly used in critical social scholarship in digital agriculture when describing these impacts. However, they are rarely conceptualized. For this reason, despite the essential contributions of this body of scholarship, there is still a limited understanding of how digital agriculture affects the life of farmers, and more precisely, their political position in the world. Based on the work of Amartya Sen, Paulo Freire, and Orlando Fals Borda, we propose a Global South perspective of these concepts, and articulate them with practices of societal control, both *through* and *of*, agricultural digital technologies. We operationalize this conceptual framework through four narratives that make an emancipatory reading of the power dynamics described on social science literature in digital agriculture. We proceed to analyze different cases where an emancipatory epistemology has been applied to cast a democratic facet of digital agriculture and conclude with recommendations to reinforce this positive trajectory.

### Keywords

Digital agriculture, emancipatory, sovereignty, agency, governance

### 2.1. Introduction

A growing body of scholarship has been concerned with the study of the politics of digital agriculture and its different representations (e.g. smart agriculture, precision agriculture, agriculture 4.0., data-driven agriculture). In rough terms, the literature portrays two coexisting political trajectories. The first trajectory - associated with productivist and techno-centric worldviews - bears the stamps of domination and polarization. The second trajectory - underpinned by relational forms of being and acting - is characterized by the liberatory possibilities of digital technologies and their democratic facet.

A digital agriculture materially and symbolically intertwined with productivist and techno-centric farming models contributes to perpetuating a corporate system at the expense of food security, local modes of life, and ecological integrity (Bronson & Knezevic, 2016; Clapp & Ruder, 2020; Wolf & Wood, 1997). Lajoie-O'Malley et al. (2020) identified a dominant institutional perspective around digital technologies, in which these technologies are part of the industrial agriculture toolkit to maximize food output. In turn, this perspective supports the status quo of unsustainable food production models, while neglecting structural changes to address social inequalities and food insecurity (Lajoie-O'Malley et al., 2020). Different authors have expressed that the same power shift from farmers to corporations that occurred through the processes of mechanization, agrochemical dependency, seed patents, and genetic modification of organisms, is now continued by digital agriculture and its asymmetrical relationships in the control of data, equipment, and infrastructures (Bronson & Knezevic, 2016; Carbonell, 2016; Carolan, 2018; Clapp & Ruder, 2020; Fraser, 2019; Hackfort, 2021; Lioutas et al., 2019; Rotz, Duncan, et al., 2019; Rotz, Gravely, et al., 2019; Wolf & Wood, 1997; Wolfert et al., 2017). Early in 1997, Wolf and Wood concluded that precision farming has been appropriated by corporations to greenwash their business models based on agrochemical dependency and the commodification of agricultural goods and services, thus contributing to rationalize unsustainable modes of production. Literature has also discussed polarizing effects of digital agriculture. For example, an increasing gap between small and large-scale capital-intensive farmers produced by asymmetrical access to technologies and technical skills (Barrett & Rose, 2022; Fraser, 2019; Rotz, Duncan, et al., 2019), or a gap between low and high skilled labor, together with marginalization of migrant racialized workers derived from the use of automation technologies (Rotz, Gravely, et al., 2019).

However, under certain socio-technical structures, digital technologies present democratizing qualities. These are underpinned by practices of collectivization as a form of sidestepping "elite capture." (Rotz et al., 2019a p. 217). Such is the case with collaborative low-cost open-source software that contributes to operating technologies outside of the control of corporations (Carbonell, 2016; Rotz, Duncan, et al., 2019; Wolfert et al., 2017). Also the group of decentralized grassroots networks for knowledge sharing (including more agroecological approaches), and digital platforms for getting visibility and coordination in struggles for rights over food, land, and technologies (Carolan, 2018; Rotz, Duncan, et al., 2019). Additionally, different forms of collective data management (data cooperatives) provide farmers with democratic and self-determined control of their agricultural data (Fraser, 2019; Rotz, Duncan, et al., 2019). Decentralized technological infrastructures also support the configuration of digital communities connecting different actors in agricultural value chains (e.g. producers, retailers, consumers) (Carolan, 2017; Hackfort, 2021), supporting relational value chains.

Farmers are at the center of these political trajectories, and the most vulnerable actor. They not only risk their livelihoods investing in these technologies (Rotz, Duncan, et al., 2019), and bear the consequences of unsuitable information, their very same modes of life, human rights, and agency, are jeopardized by exploitative and authoritarian models of digitalization. Douglas Hackney, president of Enterprise Group Ltda., expressed this idea in the following terms: “For a big data company, what is a farmer? It’s an account number... For a farmer, if their data falls into the wrong hands, it’s an existential threat.” (Gilpin, 2015 p 1). In the light of these risks, and the co-occurrence of two trajectories in digital agriculture (one oppressive and one democratizing), in this paper we propose a reexamination of the social literature in digital agriculture through an emancipatory lens.

Drawing upon Critical Theory (CT), and the work of Amartya Sen and Paulo Freire, Poveda and Roberts (2018) conceptualize development as a process to enable people to free themselves from oppression and self-determine their life. One goal of CT is to support the liberation and emancipation of oppressed populations, understanding that people exist within asymmetric power structures (Hartmann & Martin, 2021). In the intellectual tradition of CT, Marcuse (1991) expressed that, if technology has been co-opted by capitalist social forces (or emerged from these forces), there is a chance for progressive technological change under more humane social forces. In conversation with these ideas, we argue that there is transformative potential in digital agriculture. However, it requires the action of more humanist social forces than the ones rooted in productivist and techno-centric worldviews. It requires the kind of social forces that in the past inspired movements such as “Tierra y Libertad”, the Mexican revolution that strived for access to land and sovereignty, and likewise other social movements that seek the liberation of farmers from landlords, colonialists, corrupt governments, and multinational companies (Bartlett, 2008).

The concepts of sovereignty and agency – structural components of a just and dignified life, and pillars of emancipatory struggles - are commonly used in critical social scholarship in digital agriculture to describe the impact of this innovation on the life of farmers. However, with some exceptions (e.g. Carolan, 2018; Fraser, 2019), sovereignty and agency are rarely conceptualized. For this reason, despite the manifold essential contributions to critical literature on digital agriculture, there is still a limited understanding of how digital agriculture affects the life of farmers, and more particularly, their political position in the world. To address this knowledge gap, we propose a conceptual framework of sovereignty and agency based on the work of Amartya Sen, Paulo Freire, and Orlando Fals Borda. Three philosophers whose work, from and for the Global South, is centered precisely around the social struggles against injustice, domination, and oppression. We suggest that this perspective from the Global South is an important contribution to the general understanding of digital agriculture in political terms. Given the legacy of colonization and marginalization, but also liberation processes, the Global South is well positioned to assess emancipatory

and anti-emancipatory practices in digital agriculture. In our understanding, these three authors are essential exponents of these forms of thinking and acting. Amartya Sen, through his idea of development as freedom, transformed the ways of understanding development (1999). Paulo Freire devised a pedagogy to allow people to free themselves from their oppression (1970), and Orlando Fals Borda laid the foundations for a model of research and practice to decolonize the sciences, the Participatory Action Research (PAR) approach (1987; 1990).

The political trajectories of digital agriculture are engendered by discernible governance mechanisms, namely formal and informal norms and practices to regulate social interactions around technologies. Therefore, it is the task of this paper, not only to describe the consequences of digitalization for farmer's sovereignty and agency, but also the instruments that produce these consequences. Building upon the concept of techno-regulation (Leenes, 2011), and critical assessments of technology (De Filippi & Loveluck, 2016; Klerkx & Rose, 2020; Rose & Chilvers, 2018), we propose a concept of techno-governance that encompasses the varying practices of social control, both *through* and *of* digital technologies in agriculture. These practices are exercised by different human and cyber agents (smart artifacts, automated machines, algorithms), producing (or reproducing) certain political trajectories.

From the previous conceptualizations, we derived four different narratives that reexamine the social science literature on digital agriculture to articulate the work of techno-governance in emancipatory notions of sovereignty and agency. We highlight that differentiated socio-technical assemblages and power transactions occur in the spaces of governance *through* and *of* the digital. By the end of the paper, we analyze different emancipatory techno-governance practices that cast the democratic facet of digital agriculture and conclude by presenting relevant recommendations to reinforce this positive trajectory.

## **2.2. Conceptualizing sovereignty and agency from an emancipatory perspective**

Critical studies have given strong attention to the notions of sovereignty and agency in debates around human development, human rights, and empowerment-disempowerment dynamics. Regardless of this central position, critical studies in digital agriculture seldom present a conceptual framework of these notions. This condition makes it difficult to grasp what exactly is really at stake when impacts on sovereignty and agency are described in scholarship. In this paper, we propose such a framework. Drawing upon the recognition that all forms of social interference of people's inherent sovereignty and agency are dehumanizing and oppressive (Snauwaert, 2011), we turn to the emancipatory work of Sen, Freire, and Fals Borda (Table 2).

Table 2 Sovereignty and agency from an emancipatory perspective

Concept	Definition	Author	Positive and negative examples from digital agriculture
Sovereignty	Right of people to govern their own life and to live free of oppression.	Sen (1999, 1985)	Corporate technological lock-ins and exclusions.
		Freire (1970) Fals Borda (1988, 1979).	Free open-source software. Agricultural data dispossession. Voluntary regulations for responsible agricultural data management.
Agency	Capacity of people to act in pursuit of their own goals in life.	Sen (1999)	Technical efficiencies. Agricultural data co-production.
	Ability to act in the world to transform it.	Freire (1970)	Automation and labor marginalization. Corporate technological lock-ins and exclusions. Digital gap.
Critical-agency	Capacity of people to question and reject injustice.	Drèze and Sen (2002)	
	Self-determination of development priorities carried out by disadvantaged people.	Freire (1970)	Open-collaborative networks. Grassroots data management principles.
	Self-awareness of root causes of disadvantage and capacity to act on those structures to transform it.	Freire (1970)	Data cooperatives. Cyberactivism.
	Liberation from oppression and exploitation through the establishment of own political position.	Fals Borda (1987)	

### **2.2.1. Sovereignty**

Traditionally the term sovereignty has been associated with the state, and the supreme authority over a territory (Philpott, 2020). However, the existence of sovereignty at the social collective and individual level is also recognized in political discourse (Annan, 1999; Krause, 2015; Latham, 2000; Ilievski, 2021; Pierri, 2021).

Regardless of the conception of sovereignty under discussion - whether the limits of a sovereign entity are those constitutionally established for a nation, for individual liberties, or for said individual liberties collectivized by the social contract - the principles of control, freedom and legitimacy remain relevant. Moreover, the concept integrates two intertwined principles: sovereignty as capacity, and sovereignty as right. Capacity to exercise control over one's own domain (e.g. territory, social norms, life, and body), and the right for no other entity to exercise that same type of control without consent.

Throughout the work of Amartya Sen, Paulo Freire, and Orlando Fals Borda, the idea of sovereignty is continuously presented as the right of people to govern their own life and to live it free from any form of oppression. Therefore, for these authors, sovereignty is a matter of collective and individual entitlements. Echoing this perspective, different concepts appeared in the literature to delineate the boundaries for the exercise of collective and individual sovereignty. Such is the case of the concept of “body sovereignty” originated in feminist politics (Couture & Toupin, 2019), the concept of “food sovereignty”, coined by La Via Campesina (Keysar et al., 2021), and more directly linked with the matter of this paper, the concept of “digital sovereignty”. Calderón (2016) defines digital sovereignty as “an anti-establishment practice in the field of information technology, in order to integrate it in other anti-imperialist struggles” (p. 18), establishing in that way a connection with these different forms of sovereignty. For Carolan (2018), just as food sovereignty is about democratic control of popular foodscapes and community empowerment through the self-determination of their food worlds, digital sovereignty is characterized by the “democratic control of dataspace so as to empower communities to chart their own futures and define their aims” (p. 759).

### **2.2.2. Agency**

Sen and Freire have also contributed with their own conceptualizations of agency. For Sen (1999), agency is the capacity of people to act in pursuit of their own goals in life, directly linking the concepts of agency and individual sovereignty. Freire (1970), for his part, describes agency as the ability to act in the world to transform it. He also links the idea of agency with sovereignty, when introducing the concept of “critical-agency”, defined by the author as the self-determination of development priorities carried out by disadvantaged people (Freire, 1970). Critical-agency additionally involves the acknowledgement by

disadvantaged people of the root causes of disadvantage, which is combined with “their agency to act on those structures to transform their situation” (Poveda and Roberts, 2018, p. 121). When Freire presents the idea of disadvantaged people, he is directly bringing power relations to the sovereignty-agency assemblage, and it is at this point when agency becomes critical-agency. Precisely, for Freire (1970), a source of disempowerment to disadvantaged people, is the lack of awareness of their marginalized position.

In Drèze and Sen (2002), critical-agency is described as the ability to have a critical reading of existing norms and values, and to reject them if necessary. For this reason, a conceptualization of critical-agency under Sen’s perspective is presented by Poveda and Roberts (2018) as the capacity of people to question and reject injustice. Without using the expression “critical-agency” in any of his work, Fals Borda (1987) presented a concurrent idea, in which human development (the achievement of a better life) is described as the full establishment by historically dominated societies, of their own political position based on their own values and capacities, allowing them to liberate themselves from oppression and exploitation. Therefore, for Freire, Sen, and Fals Borda, the sovereignty-agency assemblage is about own action to liberate from forms of oppression.

Technologies can act as enablers or constrainers of people’s agency. Technologies become assets for human development when they can be used effectively to obtain meaningful goals in life - if willed - resulting in the expansion of human capabilities. But technology not only poses the capacity of enabling human agency, it can also originate new forms of agency and new types of agents. Bennett (2010) applies the term “vital materialism” to express the capacity of things, not only to limit the will and design of humans, but also to “act as quasi-agents or forces with trajectories, propensities, or tendencies of their own” (p. viii). In the context of digitalization, objects can be considered complete agents. It is the case of automated machines and programs which are endowed with the capacity of exerting influence over other agents, and to act autonomously in material and regulatory ways in the world. The idea of relational agency (Bajaj, 2019) is important here to express that individuals build their agency together with others (humans and non-humans), in dialogue or dispute, and through free or conditioned interactions.

Under certain socio-political structures, technologies can also be used by some actors to exert control over others, create or deepen forms of hierarchization, or to promote accumulation of influence, authority, and capital, by already powerful actors. Hoggett (2001) warned already that not all agency is good, and agency is also necessary to reproduce inequalities. Technologies can also be used to create an “oppressive world”, which Dalaqua (2020) describes as one where people are deprived of their humanity through the loss of their freedom, social hierarchization, systemic injustice, and domination by arbitrary power.

### **2.3. Techno-governance: governing through technology and governing the technology**

The term techno-regulation has been coined to describe the deliberate use of technologies to influence individual behavior (Koops, 2006; Leenes, 2011; Van Den Berg & Leenes, 2013). This concept, centered around the regulatory role of technologies in society, although useful to explore the effects of digital technologies in farmers lives, in our opinion neglects important elements, necessary to understand the mechanisms through which these effects are produced. These include the unintended societal effects of technology, and the very regulation of technologies. To incorporate these two elements, we propose instead the use of the concept of techno-governance.

Regarding digital agriculture, in our opinion there are two main instruments through which techno-governance is exercised: 1) governance *through* technology and 2), governance *of* the technology. Governance *through* technology, includes the public and private practices for political, economic, or social regulation, mediated, facilitated, or enabled by the operation of digital technologies. These practices are both, deliberately and inadvertently, exercised by humans and cyber-agents, producing intended and unintended effects. Governance *of* the technology, relates to the forms of allocating the authority to make decisions over the development and operation of digital technologies, including the rules in the cyberspace, and the distribution of property rights and access regarding infrastructure, equipment, and data<sup>2</sup>.

The complexity of technological systems and of the network of socio-technical interactions they engender or hinder facilitates a condition highlighted by critical analysis of technologies: the possibility of them to produce unintended, unexpected, and unforeseen effects, with particular political consequences (De Filippi & Loveluck, 2016; Klerkx & Rose, 2020; Rose & Chilvers, 2018). Consequences that, although uncertain, must be expected to occur (Hoffmann-Riem & Wynne, 2002). For Owen et al. (2013), technologies present very different impact profiles, as they produce simultaneous, interlinked, and multifaceted reconfigurations of social systems. Not only can technologies be relatively flexible in design, and variable in their effects (Winner, 1980), but, once introduced in society, they often evolve in unforeseen ways with the risk of being appropriated by unexpected power relations (De Filippi & Loveluck, 2016).

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<sup>2</sup> It would be possible to discuss a third instrument: “governance *for* the technology”, which covers the policies and actions implemented to allow the operation of technological systems, or to transform agricultural systems to make them more compatible with said technologies. This can include the processes of extraction and use of natural resources to obtain the materials and energy to create and operate the technologies, the development of connectivity systems, or the industrialization of farming landscapes. To present a more concise argument in this article, we will focus the discussion in the governance *through* and *of* the technology.

Beyond technical components, technological systems are also characterized by a network of actors that develop a particular institutionality to regulate their own interactions around technologies. For Okada (2006), techno-governance represents the system employed to harmonize diverse technology-related actors. Brucksch (2017) used the term techno-governance (instead of techno-government) to highlight the role of actors beyond governmental authorities, such as industry, academia, and users, in the regulation of technical artefacts and infrastructures, and the distributed action between human and non-human actors. Building upon these conceptualizations, we posit that around technologies, a network of actors, knowingly and inadvertently, develop rules of the game that define the way technologies are developed, deployed, used, and controlled. This is carried out through social norms and structures, formal regulations, industrial processes, and knowledge systems. This institutionality determines (deliberately and inadvertently) the particular ways in which technologies distribute power in society. In this paper we understand power as the capacity to influence the world and others, including the possibility of suppressing this capacity in others.

Analyzing the governance of digital technologies and their infrastructures requires analyzing novel spaces of action (cyberspace), agents (cyber-agents: devices, machines, and programs), and resources (e.g. digital data). The concept of techno-governance, as we use it in this paper, includes the process of collection, aggregation, storage, analysis, distribution and trade of digital agricultural data, the governance of this system, and its implications on the distribution of power among the different agents participating in digital agriculture. It also encompasses the agency of cyber-agents in the real world, cyberspace, and its confluence.

Practices of techno-governance do not remain undisputed by the techno-governed constituencies, who apply their own practices (in many cases making use of technological means themselves) to compensate for the loss of sovereignty and agency. The term "technological drama" has been coined by Brey (2008) to describe the dynamic that begins every time a technological system is deployed with effects on social structures and power dynamics. The process is characterized by cycles of technological and institutional adjustment by the techno-governed as a response to control and authority, and intensified iterative states of control and adjustment, until the reconfigured technological systems are either accepted or ultimately rejected. Following Swartz's categories for post-bitcoin blockchain projects (Bitcoin 2.0) (2017), the different adjustments in this technological drama can be categorized as either incorporated or radical. Incorporated adjustments do not tacitly seek the transformation of the hegemonic economic and political system, but are incorporated into it, to level the playing field. Radical responses, on the other hand, seek to replace traditional financial and political systems with alternative systems based on new social values and governance mechanisms. Therefore, they present a greater potential for transforming the root causes of farmers' disadvantage through the novel forms of agency and critical-agency.

## **2.4. Four narratives to describe the work of techno-governance over farmers' sovereignty and agency**

By using digital technologies, farmers become part of a technological system regulated by other actors, or even by the technology itself in the form of automated machines, algorithms, and code protocols. This process operates through unfolding negotiations between the sovereignty and agency of farmers, and the sovereignty and agency of other human and cyber-agents, with consequences for the lives of farmers. Below we present four narratives that reexamine social literature in digital agriculture. We focused this reading on the multi-actor power dynamics, namely the changing levels of influence, that are a consequence of the governance through and of the technology (mechanisms), and the trade-offs in terms of farmers' sovereignty and agency (effects). These narratives are our contribution to critical readings of digital agriculture and its social consequences from an emancipatory perspective (Table 3).

### **2.4.1. And agency for all...**

If agency is the capacity to act in the world to transform it, digital technologies can certainly enhance this capacity, holding great potential to be used by farmers to transform their farms. The set of applications of digital technologies in agriculture is broad and farmers can use it to regulate their practices through these technologies. Using technologies such as sensors, image processing, machine learning, and internet of things (IoT), farmers can identify pests, diseases, soil conditions, weather patterns, and maturation stages, obtain yield estimations and monitor livestock conditions and behavior (Aqeel-ur-Rehman et al., 2014; Khanal et al., 2017; Sharma et al., 2020; Wolf & Wood, 1997). Digital networks, mobile phones, databases, and Expert Systems (ES) are important channels for information exchange (Aker, 2011; Barrett & Rose, 2022; Baumüller, 2018; D. Jiménez et al., 2019). Global Navigation Satellite Systems, environmental sensors, and big data, improve the guidance and precision of farm equipment (Clapp & Ruder, 2020; Green et al., 2021; Wolf & Wood, 1997). Machine learning, artificial intelligence (AI), robots, unmanned aerial vehicles (UAVs) and variable rate application technology (VRAT) are applied to monitor animal and plant health, spray pesticides, harvest fruits and vegetables, and milk cattle more efficiently (Daum, 2021; Green et al., 2021; Tzounis et al., 2017).

Table 3 Four narratives for an emancipatory reading of digital agriculture

<b>Governance <i>through</i> technology</b>	<b>Governance <i>of</i> technology</b>
<p><b>1. And agency for all...</b></p> <p>Technical efficiencies and the enhanced agency of different actors in agrifood value chains.</p> <p>Inequalities that limit the agency and critical-agency of farmers.</p>	<p><b>3. Techno-barons, start-ups, and expropriated users</b></p> <p>The action of corporate technological lock-ins.</p> <p>New emergent authorities and institutions, and the (lack) of effects in agricultural value chains.</p>
<p><b>2. Digitalization, surveillance, and industrialism</b></p> <p>Forms of societal control through agricultural digital technologies.</p> <p>Technological gap and farmer's exclusion.</p>	<p><b>4. Harvesting the terabyte fields</b></p> <p>The data economy in which farmers participate.</p> <p>Techno-regulation corporate practices and the infringement of farmer's rights.</p>

Farmers can also make use of digital technologies to influence changes beyond their farms. Traceability opportunities of digital technologies, and their capacity to record, store, and transmit information in real-time, originated the term “hyper-transparency” (Kos & Kloppenburg, 2019). This possibility is proclaimed by organizations and companies as the ultimate way to enhance farmer’s capacity to participate and strengthen their position in agrifood value chains, and to coordinate their action with other stakeholders. Traceability through digital tools and networks facilitates the recording and communication of quality attributes, agricultural practices, provenance, and other types of information related to production. In turn, this information can provide farmers with new forms of visibility and trustworthiness to participate in markets and access services, such as credit, crop insurance or banking (Casado-Vara et al., 2018; Kamilaris et al., 2019). The possibilities of multidirectional information exchange can even provide farmers with a better understanding of the value chains, improving their decision making and risk management possibilities.

Digital marketplaces and smart contracts (self-executed protocols) have been implemented to connect farmers with buyers and establish commercial relationships, potentially reducing disintermediation and transaction costs, facilitating more value capture by farmers who participate in such schemes. Moreover,

the reduction of transaction costs and optimized coordination through digital platforms and systems allows smallholder farmers and small rural enterprises to organize themselves, coordinate with each other, and be more competitive (G. Prause & Boevsky, 2019).

Not only farmers, but also other actors in agricultural value chains enhance their own agency through the use of digital technologies and digital data. It is the case of agricultural service and input providers, governments, financial institutions, researchers, and activists, using production information collected through digital tools and digital platforms to orient their actions and strengthen their services (Namyenya et al., 2022), and guide the development of agricultural policies (Ali et al., 2020; C. R. Eastwood et al., 2023; Ehlers et al., 2022). Smart contracts, and their possibility to verify compliance in agreements between different actors in agrifood chains without the need for a third party, are promoted as a tool to counteract informality and exploitation within the sector (Pinna & Ibba, 2017). Digital traceability has also been applied in processes of land governance. Pfeifer et al. (2020) reported the use of digital traceability systems to facilitate land registration and transaction processes in countries such as Brazil, Indonesia, India, and Rwanda. The idea is to use transparency and efficiency to provide new opportunities for rural communities concerning land formalization and to support their claim of rights over the land.

After this description, in the frame of an emancipatory perspective, it is important to question how all these potentialities are really transforming the agricultural world in a meaningful way. In light of Sen, Freyre, and Fals Borda, this agency would mean the transformation of structural inequalities in agriculture. Most global agricultural production takes place on small farms (Abraham & Pingali, 2020). Lowder et al. (2016) reported that about 84% of the 570 million farms in the world are less than two hectares in size, with many of these smallholder farmers living in poverty. Given the substantial gaps (e.g. low internet coverage, prohibitive costs of technologies and data) that remain in these rural areas (Mehrabi et al., 2020), it is reasonable to expect difficulties for most farmers, especially the most disadvantaged, to reap the benefits of digitalization. It is also possible that despite the enhanced data flow, the information asymmetry between producers and other actors in the agricultural value chains (traders, processors, regulators, consumers) remain unchanged. Traceability systems are currently designed to provide large amounts of origin information (e.g. location, agricultural practices, sustainability indicators, farmgate prices) without returning similar levels of information to producers. It is worth asking in what proportion implementation of “hyper-transparency” is the result of farmers' true goals, and in what proportion it is a response to a growing culture of scrutiny that undermines farmer's sovereignty. Also, it would be important to ask how willing actors in other stages of the value chain are to be 'hyper-transparent', or if transparency only applies to farmers.

Currently, the concentrated agency of powerful players such as large retailers, manufacturers, and agri-tech corporations, seems unchallenged by digital agriculture. An analysis in the coffee value chain (Hidalgo et

al., 2023) identified that producers continue to be a large and dispersed group, competing with each other in online platforms, to access a small and consolidating number of processors and traders. Consequently, farmers are not getting real decision capacity over farmgate prices, only more information to navigate the existing dynamics. Instead of revolutionary, for the authors, digitalization is about increased efficiency within already centralized power structures. Farmers continue selling raw materials, while the larger portion of the value of agricultural products is still captured in other stages of the value chain and by better-off actors. Technological advancements, such as low-budget sensors, and mobile-phones, are supporting the participation of smallholder farmers in the digital transformation (Aker, 2011; Baumüller, 2018; Coggins et al., 2022; Daum et al., 2022; Duncombe, 2016; Emeana et al., 2020), however, these tools are doing little for changing power asymmetries. For these reasons, the root causes of disadvantage for millions of farmers in the world remain untouched by the process of digitalization.

Despite the prospects, important barriers persist for digital technologies to represent a true transformation of the conditions of disadvantage of millions of farmers in the world. But could digital agriculture also be a scenario for the exercise of new forms of oppression? The following narratives are focused on discussing this possibility.

#### **2.4.2. Digitalization, surveillance, and industrialism**

Agency is relational, meaning that farmers' agency is also a result of the reconfiguration of the agency of other actors that takes place through digitalization. A reconfiguration that can result in the transgression of farmers' sovereignty or the loss of their agency. The novel forms of information management represented by digital traceability and smart farming exemplifies this process, with corporations, governments, and elites, having the possibility of using "hyper-transparency" and precision farming technologies, to govern farmers through technologies, exercising new forms of surveillance, control, and dispossession.

The credit score implemented in China, the powerful machine of governmental surveillance revealed by Edward Snowden, and the Cambridge Analytica case, demonstrate the risks for public sovereignty and agency posed by the abuse of digital technologies by powerful actors. Traceability systems and precision farming technologies (e.g. satellites, smart tractors, drones, robots, AI), with their capacity of reading the quality of every piece of land on a millimetric scale and recording important elements of human physical and digital behavior, can create their own oppressive rural scenarios. Farmers have already started to express concerns about drones taking pictures of their private lives (Thompson, 2019). In the UK, public concerns have emerged over the possibility of the government applying blockchain technology to monitor individual expenditures (Cellan-Jones, 2016). Something similar could happen to control the expenditure of

agricultural subsidies or loans. Location information and AI technology can be used by governments to target dissidents or minorities (Seyedsayamdost & Vanderwal, 2020). Digital platforms and networks can be used to distribute targeted political propaganda within rural communities. Digital technologies can also be used to increase surveillance over farm workers, creating more repressive work environments. This surveillance can be applied, for example, to limit the possibility of farm workers to organize collectively (Hackfort, 2021). The identification of valuable resources and lands with special attributes can boost land dispossession, extractivist economies, and land speculation. Digital gaps extend asymmetrically the agency of elites in this regard. In their analysis of digital land-governance, Pfeifer et al. (2020) identified that these systems not only failed to address systemic problems of corruption, marginalization and speculation, but even contributed to deepening them. Corporations and big landowners promoted land marketization and legalized many land grabs through fraudulent digital registries (Ibid). Not only the most disadvantaged farmers are precluded from using digital technologies to build their own agency, but the potentialities of these technologies are also used by powerful actors to infringe their sovereignty, apply new forms of oppression, and consolidate their privileged position.

Digitalization also promoted the conditions for the control of farmers by technologies themselves, or the competition between farmers' agency and the agency of cyber-agents. Displacement of rural labor by processes of digitalization and automation, for example, affects especially more marginalized groups (e.g. seasonal workers, illiterate people, women). Rotz et al. (2019b) reported a high-skill/low-skilled labor market bifurcation, with new opportunities for techno-savvy professionals, and displacement of low-skilled workers. Meanwhile, precarious conditions and exploitative practices in rural labor persist in many parts of the world without being challenged by digitalization. Farmers also lose agency and sovereignty through the loss of skills and autonomy that occurs with more mediation of technology in rural labor (Carolan, 2018; Ingram & Maye, 2020; Rose et al., 2021; Rotz, Gravely, et al., 2019). Some farmers reported concerns about becoming dependent on technology, and the disruption of human-land relations (Kaler & Ruston, 2019; Rose et al., 2018). Users of digital technologies have seen their work subordinated to the demands of automated systems. Hansen (2015), for example, describes a change in routines associated with automated milking systems, with farmers required to be permanently on call to respond to robot alerts.

Smart contracts also subject farmers to the rule of cyber-agents, establishing a case of "algorithmic authority", in which human action is replaced by the action and direction of algorithms (Lustig and Nardi, 2015); a system in which farmers have little to no influence. It has been argued that algorithmic verification can help to curve exploitative practices (Pinna & Ibba, 2017). In practice, algorithms can also serve to reinforce these practices. In other words, a contract based on unfair conditions does not cease to be unfair just because it is enforced by an algorithm, and structural asymmetries can be translated into code. After all,

algorithms are coded by humans (a rapidly changing scenario thanks to AI), and are imbued with human values, including biases, subjectivities, and intentionality. Algorithms can even reinforce exploitation more categorically than human agents, since they perform no matter what, and agreements cannot be negotiated or adapted without modifying the code, a possibility in the hands only of the ones controlling the system and those with technical capacity.

These different forms of control and oppression exerted by human and cyber-agents are promoted by at least two different worldviews shared by techno-governors. In the first worldview, farmers are perceived as a group without sovereignty, that can be controlled and exploited through surveillance and techno-opportunism (taking advantage of the digital gap to exploit disadvantaged farmers). The second, regardless of the consequences on their opportunities and goals, perceives that the work of farmers (a key component of their agency) should be replaced by that of machines, in favor of efficiency and sales of technology. Under the techno-centric and productivist perspective that seems to dominate the practice and narratives around digital agriculture (Bronson, 2018; Bronson & Knezevic, 2016; Kuch et al., 2020; Rotz, Gravelly, et al., 2019; Wolf & Wood, 1997), farms are conceived as places where people do not need and do not want to be (Baur & Iles, 2023), or systems that can be managed remotely by a single person supported by the action of smart tractors, sensors, and other technologies not yet existent (Bronson, 2018). This is a perspective that challenges the very idea of what a farmer and what farming is. The assemblage of industry, liberalism, and technoscientific capitalism (Birch et al., 2020) leaves little room for the agency of smallholder farmers, and for those who do not want to transit to industrial production models, and undermines the self-determination of priorities that direct digital innovation. Smart farming, as currently conceived and implemented, is predominantly tailored to support monocultural industrial farms, with little use for agroecological smallholder farmers (Carbonell, 2016). Bronson (2019, 2018) describes that the design of smart farming technologies is commonly oriented towards solving problems faced by large-scale industrialized producers, who have the capacity to pay for said technologies. Meanwhile, the potential harmonization between digital technologies and agroecological approaches is neglected.

### **2.4.3. Techno-barons, start-ups, and expropriated users**

The possibility of farmers to participate in the governance of digital agriculture and to direct this innovation to the pursuit of their goals is strongly threatened by centralized control of these technologies. A structure that mirrors the ongoing corporate food regime. Critical assessments of digitalization in agriculture warn about the concentration of power in the hands of few actors (Klerkx & Rose, 2020), operating under logics of rentier capitalism and accumulation (Birch et al., 2020; Fraser, 2019; Rotz, Duncan, et al., 2019; Rotz, Gravelly, et al., 2019). An oligopolistic structure is configured around agri-tech corporations such as Bayer-

Monsanto, John Deere, Dupont, Syngenta and DOW (Bronson, 2022; Clapp & Ruder, 2020; Fraser, 2019; Wolf & Wood, 1997; Wolfert et al., 2017), and tech corporations that provide cloud computing services such as Google, Amazon, Microsoft, and IBM (Birch et al., 2020; Fraser, 2019; Rogerson & Parry, 2020; Wolfert et al., 2017). Alliances between these corporations expand corporative domination and further power accumulation. Such is the case of Microsoft signing deals with Bayer-Monsanto to control large amounts of agricultural data on the platform Azure Data Manager (Hackfort, 2023).

Sovereignty as the right of farmers to govern the technologies they acquire, and agency as the capacity of unrestrictedly operating their technologies, are in serious peril by the techno-governance strategies allowed by this centralized structure and by the accumulation of corporative power. These corporations maintain control of technologies through property claims based on public and private regulations (and associations of these two), that give them ownership of the devices and machines purchased and used by farmers. The US Digital Millennium Copyright Act, for example, made it illegal for an owner to access their tractor's engine control unit (Carolan, 2018). In the same line, John Deere, together with General Motors, set a copyright claim that makes it illegal for farmers to access and modify the software in their tractors (Wiens, 2015). Climate Corp., property of Bayer-Monsanto, through their end user license, determined that farmers couldn't access and modify their products (Carbonell, 2016). The aim is to keep farmers captured in a cycle of dependency and payments for parts and technical assistance. Under the logics of rentier capitalism and accumulation that govern this corporative system, more than users, farmers are rather conceived as a market, that, through a technical lock-in, generate large profits as buyers (renters) of products and services.

The broad scope of technical possibilities, the big market for digital technologies, the development of more efficient technologies at a lower cost, and a strong impetus for digital innovation, have contributed to the emergence of a constellation of new actors in the digital economy. Tech start-ups are at the center of this constellation, sharing the space with large corporations, and challenging their dominant position. And although more distributed control of digital technology can provide a space for the representation of a greater diversity of perspectives, and for farmers' voices to be heard, it would not necessarily be enough to transform the power asymmetries that generate conditions of disadvantage for farmers. Many start-ups also operate under the logic of rentier capitalism, seeking similar strategies to corporations for profit generation. In some cases, they are competing to become the next agri-tech corporation. On many more occasions, these start-ups, especially those presenting promising possibilities for profit generation, are acquired by large corporations, creating a renewed wave of corporate consolidation. Such is the case of the start-ups such as Climate Corp., 640 Labs, and VitalFields, all acquired by Bayer-Monsanto (Bronson & Knezevic, 2016). As a result, the same exploitative practices around the control and ownership of technologies can be

practiced by start-ups in search of extracting value from farmers, or they can be incorporated to fuel a trajectory of techno domination.

The use of algorithms to verify information, and platforms such as digital marketplaces or traceability chains, have been promoted as the ultimate tools for disintermediation, replacing the need for human verification, and opening channels for more direct trade. The emancipatory potential of these technologies, however, is limited. The promise of liberating farmers from the yoke of intermediaries, in practice, can be an opportunity for new forms of intermediation and power centralization in the hands of actors other than farmers. Despite the promises of autonomy and democratization, in reality, these systems require the action of administrators, developers, programmers, and coders. These actors, in turn, acquire new authority over digital infrastructures. They define the rules of the system, including who participates, what are the possibilities for participants, and how value is extracted and distributed (Veen, 2021). More than a process of disintermediation, what occurs is a reconfiguration of intermediaries, or a reintermediation, with traditional actors such as brokers, aggregators, and financial institutions, replaced by tech-savvy entrepreneurs. The work of these new controllers is often backed by companies with specific agendas, which challenges the neutrality and ethics of such systems (Tang et al., 2019). The risks are that these systems can be a way to exert power based on technological authority, rather than a force of democratic participation for collective interest (Ertz & Arsenault, 2019). Meanwhile, the position of farmers, and their agentic capacities remain unaltered. In other words, these systems can become extended forms for extracting, rather than providing, value from farmers. Once again, it is arguable if these systems can really operate to dismantle the forms of oppression facing disadvantaged farmers, or if they just constitute alternative and extended forms of techno capitalism.

#### **2.4.4. Harvesting the terabyte fields**

Digital technologies create a new space for the practice of techno-governance. The data economy: the system of data control and the extraction of value from it, including the processes of collection, processing, and exchange, and the network of actors that participate in these processes. In the data economy, farmers as individuals or in collectives, are not only users, but also co-producers (Lioutas et al., 2019). Farmers contribute to the large pool of digital agricultural data every time they use digital technologies, transforming the datascape (to use Carolan's term<sup>3</sup>) in quantitative and qualitative ways. This dual role of farmers, and

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<sup>3</sup> Carolan (2018) vaguely uses the term when conceptualizing digital sovereignty and the interlinkage with the foodscapes inherent to food sovereignty. Here we return to the term to describe the product of agricultural data aggregation, which has attributes other than the simple sum of individual data sets.

the ownership dynamics associated to this co-production, in turn, draws a particular scenario for the protection, exercise, or transgression of farmers' sovereignty, and agency.

That farmers (and users in general) co-construct technologies through use, meaning, and adaptation has been previously addressed (Higgins et al., 2017; Rose et al., 2018; Van Der Burg et al., 2019). The case of agricultural data is no different. However, it presents some particularities. The data generated by the particular use given to digital technologies by farmers has profound effects on the general pool of agricultural data (Lioutas et al., 2019). Datascape are the result of aggregating the data generated individually by each farmer through their agri-digital practices, that is, the fruit of their labor. This process unequivocally entitles farmers with certain grades of ownership and rights over this data and is a call for having them as participants in its governance. The process of co-construction can be read as a clear expression of farmer's agency, with the (cyber)world being continually transformed by their action, and for all participants in the data economy. Additionally, the co-construction of datascape is not a slow and gradual process, such as other cases of technological co-construction, but rather immediate, in real time, transforming these datascape second by second. This represents a challenge for the responsible governance of the data economy. The object of regulation (agricultural datascape) is continuously reconfigured, changing in nature and quantity, trespassing national boundaries and regulations, and changing hands (servers) in an instant. These co-constructed datascape are used with the same immediacy in which they are generated by multiple actors, not only for the management of the farms, but also as a source of profit and dominance.

The terms "commodification" (Wolf & Wood, 1997), or "assetization" (Birch et al., 2020) have been applied to express the process in which agricultural data (product of farmers labor) is treated as merchandise. In this process, agri-tech and tech corporations, with their capacity of aggregating and processing immense amounts of data, are usually involved (Carolan, 2017; Fraser, 2019; L. Prause et al., 2021; Wolfert et al., 2017). What constitutes the value of data for corporate actors is at the same time a cause of sovereignty transgression for farm actors. Seed, chemical, insurance, machinery, and trading companies are highly interested in the predictive power of big data, and the possibilities of using it for market speculation (Fraser, 2019; Kritikos, 2017), to control the direction of agricultural innovation (Kritikos, 2017), or to target farmers with unrequested advertising (Bronson, 2019; Hackfort, 2021). The peril for farmers' sovereignty does not only lie in this process of commodification. The problem does not merely arises from the use of their data, but also from the fact that all this process occurs without farmers being aware of it. Farmers inadvertently participate in the data economy, and they are mostly unaware of the way their data is stored, processed, and traded (Carbonell, 2016; Fraser, 2019; Kritikos, 2017; Van Der Burg et al., 2021). This results in farmers being generally unaware of what information is being collected, who has access to it, how the information

is used, and what are the consequences of this use, including the value generated for other actors. In Freirean terms, the exercise of critical-agency by farmers is totally undermined: they are inadvertently participating in a system that exploits them.

The governance of agricultural data is not only reinforcing the perspective of farmers as a market. The same actors that profit from this system, use and take advantage of different techno-governance mechanisms to dispossess farmers of their data, and consequently from the value generated. The possibility of governing their data is removed from farmers through a process of ownership dispossession labeled as “data grab” (Fraser, 2019). User license agreements created to regulate ownership, become instruments to institutionalize said dispossession and privatize information. A process especially favored by the embodiment of these regulations in the form of intricated legal documents in the language of the technology provider, which are hardly understood by a rural population, who may be in some cases illiterate. These regulations can be modified by the action of a simple clause, forcing farmers to maintain continuous watch to track changes to the legal provisions or face the risk of infringing corporate mandates. Additionally, big gaps exist in license agreements, leaving data sovereignty highly vulnerable and data grabbers unaccountable. Studies have shown that corporate privacy agreements of digital agriculture technologies commonly fail to disclose the use of agricultural data by corporations and third parties (Bronson, 2019). Hackfort (2021) argues that many digital platforms obscure their back-end processes and withhold data use information. A single clause can make personal data readily accessible to governments, agencies, investors, and companies, on the basis of the company’s ‘legitimate interests’ or ‘business structure’, to use the jargon of these documents.

Dispossessing farmers of data control through transfer of ownership and privatization is the mechanism by which farmers are dispossessed of the value of information, and subjected to the imposition of technocratic capitalism, instead of possible democratic forms of data governance. The profit derived from data is not shared with the farmers, even though it is based on the data generated by their labor. Additionally, asymmetries in technical and analytical capacities compromise farmers’ agency in regards to data control and access to value. These asymmetries create patterns of exclusion, where farmers are not only deprived of access to the great pool of information to which they have themselves contributed, but also to the benefits derived from its use. The problem is not necessarily an issue of access to the data. Farmers often do not have the technological capacity and technical expertise to effectively exploit agricultural big data (Carbonell, 2016; Mittelstadt & Floridi, 2016). The issue is a problem of access to the value. Exploitation and profit remain in the hands of only the few with the capacities to deal with the complexities of big data (Kritikos, 2017; Lioutas et al., 2019). These are “those with access to the machines, the databases, and the algorithms” (Andrejevic, 2014 p. 1676).

## **2.5. Loosening the knot. Answering claims for sovereignty and agency in and with the digital space**

Although the techno-governance system of digital agriculture is a space for new forms of oppression, the same system is witnessing the emergence of forms of resistance and fulfillment for farmers, answering their claims of sovereignty and agency, and reconfiguring social networks in the process.

Farmers are dispossessed of their data by corporations, and the risk of their personal information being misused is real. End-user licenses and privacy agreements have mainly contributed to this process, and to obfuscate the mechanisms of dispossession from public understanding. Thus, it has been necessary to implement various regulations to prevent these practices, or at least make them more visible. The General Data Protection Regulation adopted by the EU (Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the Protection of Natural Persons with Regard to the Processing of Personal Data and on the Free Movement of Such Data, and Repealing Directive 95/46/EC (General Data Protection Regulation), 2016) is an example of formal regulations addressing issues around privacy and personal data for the public in general. Many other countries have developed their own data protection policy or are in the process of creating one. However, these regulations do not address the issue of agricultural data. To protect digital sovereignty regarding agricultural data (which includes personal and non-personal data), coalitions of farmers, associative groups, agri-tech companies, government institutions, and third sector organizations, have developed a diverse array of principles, codes of conduct, guidelines, and accreditations, to partially disclose the use of agricultural data by companies, and to give farmers greater possibilities for decision about their data. Examples of these regulations include the Privacy and Security Principles of Farm Data and the Ag Data Transparent Certification in the USA, the Farm Data Accreditation and Farm Data Code of Practice in New Zealand, and the EU Code of Conduct on Agricultural Data Sharing by Contractual Agreement.

Following Swartz's incorporated/radical categories (2017), these regulations can be described as incorporated responses to data exploitation. More than the transformation of the techno-capitalist system that engenders oppressive structures, they aim to discipline it. Through these regulations, mechanisms of exploitation are partially disclosed, or consent is requested, and farmers, through ownership, are invited to participate as controllers of their own data. However, under the lens of those voluntary regulations, data continues to be perceived as merchandise; a good subject to the logics of privatization, rentiership, and false scarcity<sup>4</sup>. In turn, the agency of farmers under these regulations is limited to the boundaries of the capitalist

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<sup>4</sup> An unreflective perception inherited from extractivist economies in which the value of data is conceived as finite, depletable, and should be exploited by a limited number of actors. It is not fortuitous the already commonplace, but rather inappropriate, use of the metaphor of data as the new oil.

system and its values, and therefore the possibilities for transformation -especially of the causes of oppression rooted in this system- are tempered.

Contrastingly, ‘bottom-up’, ‘solidarity’, ‘commons economy’, ‘not-for-profit’, and ‘open’, are badges that can be attached to a different set of techno-governance practices and spaces associated with the radical trajectory described by Swartz (2017). Those are expressions of post-capitalist -not yet a system- projects representing clear manifestations of critical-agency. These are projects that dialogue without using the codes of profitism, competition, private property, and accumulation. These projects embody grassroots struggles for sovereignty (now including digital sovereignty), and creative forms of agency. At the same time, they enroll important advocates from different sectors of society in these causes, creating novel partnerships. It could be argued that these projects are in resonance with what Carolan (2017) described as “politics of addition”, a call for practices and discourses that engender novelty and multiplicity, instead of “subtracting” these opportunities.

These projects are embodied by digital communities, data cooperatives, cyber activism, and software; all of them with something in common: the goal of operating outside corporate and government control and embracing more democratic forms of organization. The System for Rice Intensification (SRI) Community of Practice, for example, is a community of farmers, researchers, and technicians, dedicated to share information online to improve rice yield while reducing the reliance on external inputs provided by corporations such as seeds, fertilizers, or pesticides (Styger, 2015). This platform was created with the support of Cornell University, and currently runs without the sponsorship of governments or corporations (Bollier, 2017). Farm Hack is a community of farmers, designers, developers, engineers, architects, and roboticists (Cox, 2016), who stand up for the agricultural traditions of “tinkering, inventing, fabricating, tweaking, and improving things that break” (Farm Hack, n.d.). This community is dedicated to building and modifying their own farming tools and building an ever growing online open-access repository of agricultural tools and practices (Cox, 2016). The Right-to-Repair movement is a coalition of multiple organizations and citizens, mobilizing collective capacity to advocate for the right to self-repair products, and to make it affordable and accessible (Right to Repair, n.d.). Moreover, some examples of emancipatory software are the open-source tools for farm management such as LiteFarm, farmOS, and Open Food Network, which provide farmers with free and customizable solutions outside of corporate control.

Different data governance projects are starting to understand data as a common good and not as a private asset. There is also the case of initiatives to endow farmers, and other grassroots collectives, total sovereignty and agency over their data, in conversation with the logic of collective good. Data “crowdsourcing” or the voluntary donation of data for collective causes is one example of such commons data economy. The crowdsourcing of data has been reported in diverse areas such as bird counts, climate

change impacts, crop variety performance and traits, and pest outbreaks, to support agricultural citizen science (Wittman et al., 2020). Farmer's data cooperatives are emerging to grant farmers greater control of their data, and very importantly, equitable access to the value created. New Vision Coop and the Grower Information Services Cooperative are two of these farmers' organizations, where farmers keep control of their data throughout the whole process of collection, processing, and transmission. The cooperative generates value from the common pool and distributes it among the associates according to their level of contribution to the collective repository (Giagnocavo & Hernández, 2019).

Not directly in the agricultural sector, but representing an important reference case, are the Ownership, Control, Access and Possession (OCAP™) principles. This is a set of principles elaborated by First Nations groups in Canada to protect their right to control the information about the First Nations (The First Nations Information Governance Centre, 2014). OCAP™ has been described as “a political response to colonialism and the role of knowledge production in reproducing colonial relations.” (Espey, 2002). OCAP™ is an expression of critical-agency, as it is a response that arises from the acknowledgement of the root causes of disadvantage. The story of colonization has strong parallelisms with the case of farmers and the exploitation of their data by corporations. Some of the grievances expressed by these groups in the OCAP™ document (The First Nations Information Governance Centre, 2014) illustrate this. These include: Gathering of their data without their consent; lack of influence over the use or disclosure of their data; the analysis, interpretation, and reporting of First Nations data without consent, approval, or review; profit generated with their data without compensation; the treatment of First Nations as mere sources of data; and the lack of explanation of the studies on First Nations' language or in a “manner adequate to ensure fully informed consent.” (p 7).

Digital technologies are not only being used by farmers and advocates to answer the claims for digital sovereignty, or to expand their agency in digital spaces, they are also an instrument to answer farmer's claims of sovereignty in the analog world, and tools for struggles beyond the management of data. An example of this is the case of cyberactivism for agrarian causes such as food sovereignty, land sovereignty, agroecology, and climate justice. Worldwide, the possibilities of coordination, information sharing, visibility, and decentralization, provided by digital media, platforms, and forums, are being used to raise attention over socio-environmental conflicts, inform the public, and gain allies and influence. In summary, digital technologies are contributing to developing critical-agency, through awareness, social coordination, and influence to transform the root causes of disadvantage. La Via Campesina, for example, has mobilized important digital resources such as videos, social media, blog posts, newsletters, among others, to create a strong online presence to advocate for their struggles for food sovereignty and land sovereignty (Fraser, 2020). The Global Atlas of Environmental Justice (EJAtlas) is a digital platform to map and document social

conflicts around environmental issues worldwide, in the endeavor of making corporations and states accountable for the injustices inflicted through their activities (EJAtlas, n.d.). The platform, by March 2024, was documenting 3980 open cases, of which 683 involve farming communities (Dell'Angelo et al., 2021). In the words of Leah Temper, the founder and co-director of the platform, EJAtlas “documents resistance to extractivism and to toxic pollution, territorial defense by peasants and indigenous communities against mines, dams, coercive conservation projects and deforestation, protests of urban and rural dwellers against mega-projects, military and energy infrastructure and gentrification as well as conflicts over waste disposal such as opposition to landfills, incinerators, also climate justice movements and opponents of false solutions such as geo-engineering” (Temper et al., 2018).

The examples presented above show that the same historical struggles for justice, sovereignty, and freedom, are now transferred to digital spaces. Beyond a technological drama, the techno-governance system of digital technologies, in reality, reflects the ongoing societal drama between different political and economic systems, some that engender oppressive structures, others that engender egalitarian and liberating ones. Paraphrasing Carolan (2017), digital technologies in this process are instruments for different human purposes, these can be additive for different forms of agency of the disadvantaged, or subtractive of this possibility.

## **2.6. Conclusion**

The techno-governance system of digital agriculture is an assemblage of multiple agencies of human and cyber agents. The socio-technical interactions in this assemblage result simultaneously in sovereignty and agency gains and losses for farmers - a complex set of power transactions in which farmers participate many times inadvertently. Certainly, there are important opportunities for the expansion of farmer's agency. However, the dominant trajectory of digital agriculture seems to fail in transforming the root causes of their disadvantage. Instead, it may be reproducing different forms of oppression. A techno capitalist model driven by corporations uses technological lock-ins to extract value from farmers without adequate compensation. At the same time, there are growing possibilities to establish political regimes of surveillance. In response, farmers and advocates, apply incorporative and radical emancipatory practices of techno-governance with differential transformative capacity.

Holloway and Fernández-Savater (2015) argue that the world is full of cracks through which it is possible to do things differently, for example, activities that are not subordinated to the logic of profit. An emancipatory endeavor would be to open and widen these cracks in oppressive systems. Precisely that has been the work of radical projects and their operation outside the control and codes of techno capitalism.

Discussing Farm Hack community, Cox (2016) expressed that hacking means “rejecting the norms of consumer culture, and imagining ways to modify, improvise, and create new, accessible, custom solutions” (p 1). Following this definition, we concur that hacking is simultaneously a valuable act of ‘cracking’. Something impossible to achieve without the accomplishment of critical-agency.

It is proven that digital technologies can be emancipatory. However, to achieve this potential, it is necessary that beyond immediate practical needs or market solutions, they can be used to identify and tackle the root causes of disadvantage (Poveda & Roberts, 2018). Following Sens’ ideas of agency, to be truly revolutionary, digital technologies should be tools to critically assess the world and to reject the norms and values that create injustice. This struggle (also described as drama) unfolds through emancipatory responses of technological re-appropriation that clash with practices of dominance *through* and *of* digital technologies.

The term “conscientização” (conscientization), is extensively used in Freire’s work to define an epistemology that allows disadvantaged people to “effect a more critical reading of the world” (Ledwith, 2005). Important questions that frame this epistemology are: “Why does inequality exist?” or “Who benefits?” (Freire, 1970). In a similar fashion, Geuss (1999) uses the term “enlightenment” to define the process of perceiving what interests are being served by existing social systems. Throughout the four narratives, we contribute to answering these questions in the context of digital agriculture, and additionally – loosely - map where this epistemology is used already. The aim is to spark further discussions towards a digital conscientização, presenting sovereignty and agency as valuable conceptual pillars, now in connection with rights over equipment, infrastructures, and data. Moreover, we suggest that Freire’s pedagogy of the oppressed, and Fals Bordas’s Participatory Action Research (PAR), with their emancipatory approach, can be relevant methodological contributions from the Global South to advance in the search of a critical-agency of the digital with the participation of farmers.

Awareness alone, however, cannot produce the necessary change. Opening the cracks (or practicing the hacks) requires new political and economic relationships. The transformation calls for a new social contract around technologies that takes the humanistic vows that the capitalist system is not willing to take. More than technical fixes, digital agriculture is calling for a strong political commitment to stop seeing farmers as markets or vassals of the techno-barons, and start seeing them as users, co-producers, and free citizens.

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### 3. Digitalization, sustainability, and coffee. Opportunities and challenges for agricultural development

Hidalgo, F., Quiñones-Ruiz, X. F., Birkenberg, A., Daum, T., Bosch, C., Hirsch, P., & Birner, R. (2023). Digitalization, sustainability, and coffee. Opportunities and challenges for agricultural development. *Agricultural Systems*, 208, 103660. <https://doi.org/10.1016/j.agsy.2023.103660>

#### Abstract

Digital technologies have the potential to address several sustainability challenges of the coffee value chain. However, given potential backlash consequences, this process must be assessed thoroughly. Descriptions of digital tools designed for this value chain have been presented in the literature, however, a critical examination of socio-environmental consequences of the process of digitalization is still lacking. Using a socio-technical approach, this article examines innovation pathways proposed by the process of digitalization in the coffee value chain and identifies the opportunities and challenges of these pathways to contribute to sustainability goals in this value chain. Technical characteristics of 20 digital tools oriented to the coffee producing sector are examined. We carried out a review of secondary information and conducted on-line semi-structured interviews with developers of these tools. Qualitative analyses of these characteristics were conducted across three themes: 1) knowledge and value systems represented, 2) power structures, 3) effective use of digital technology. Our analysis identified two digitalization pathways that are likely to affect different dimensions of sustainability. On the one hand, digital advisory services are focused on the diffusion of conventional agricultural practices to optimize production for a commodity market. On the other hand, trade platforms and traceability systems are associated with enhanced visibility of producers to facilitate their participation in differentiated markets. However, access barriers to technologies create asymmetrical participation of producers in these scenarios. Additionally, evidence shows that, more than a revolution, digitalization of the coffee value chain is about optimization of production based on the use of synthetic inputs and of traditional extension models, and more efficient social coordination within already centralized power structures. The analytical framework based on the technical characteristics of digital tools and their interaction with social systems revealed that sustainability outcomes derived from the process of digitalization in the coffee value chain are far from being straightforward. Considering digital technologies, not as a homogeneous category, but as a configuration of different technical arrays, each one with distinctive patterns and impacts, provides a more nuanced understanding of the role of digitalization for agricultural development.

**Keywords:** Digital agriculture, coffee, value chains, sustainable agriculture

### **3.1. Introduction**

Coffee is a high-profile agricultural value chain that provides a livelihood for millions of smallholder producers in the Global South (Borrella et al., 2015), and configures one of the largest agroindustries in the world, connecting different geographical regions and actors on a global scale (Grabs, 2020). At the same time, the value chain is characterized by several challenges that undermine its sustainability, understanding that the concept encompasses the environmental, the social and the economic dimension (Gibson, 2001). Taking these dimensions into account, the challenges along the coffee value chain (CVC) are associated to poverty in the producing sector (Sachs et al., 2019), power and information asymmetries (Civera et al., 2019; Lerner et al., 2021), impacts on productivity (Clay et al., 2018; Rodrigues and Almeida, 2020), and environmental issues related to the footprint of production (ICO, 2020), and vulnerability to climate change (Civera et al., 2019; Verburg et al., 2019). Addressing these challenges has been recognized as a relevant goal in alignment with the United Nations' Sustainable Development Goals (UNCTAD, 2015).

Digital technologies have been portrayed as one promising solution to address several of these challenges. It has been proposed that these technologies can enable producers to use resources more efficiently, increase productivity and reduce environmental footprint through data-driven management (Sharma et al., 2020). Additionally, these technologies may promote learning processes (Baumüller, 2018), and enhance transparency in agricultural value chains (Kos and Kloppenburg, 2019). A systematic literature review on the application of digital technologies in the coffee sector revealed that these technologies are gaining momentum and present important opportunities to improve productivity, quality, and sustainability (Sott et al., 2020). However, beyond promising opportunities, these technologies may also present unintended and unwanted societal and environmental consequences (Stilgoe et al., 2013; Rose and Chilvers, 2018). Previous assessments have argued that digital technologies can reinforce unsustainable production models, legitimating dependency on synthetic inputs (Wolf and Wood, 1997), expand power centralization in the hands of dominant actors (Wolfert et al., 2017; Klerkx and Rose, 2020), or erode farming identities and the connection of farmers with the landscape (Carolan, 2016; Rose et al., 2018). Such reflections around these potentially harmful repercussions encouraged a growing critical scrutiny of the impact of agricultural digitalization on people, institutions, animals, and ecosystems (Klerkx et al., 2019), and these potential effects are starting to be more seriously considered in policy (Rose and Chilvers, 2018).

Given the dual nature of technologies and their possibilities to produce both benefits and risks (Beck, 1992), and the peril of, dazzled with promises of innovation, overlooking potential harms (Nordmann, 2014), it is relevant to apply a deliberative approach and create new knowledge to examine and guide innovation processes (Eastwood et al., 2019). The application of this kind of critical analysis to examine the process of

digitalization in the CVC is still lacking, and the pathways toward sustainability that this technological transformation is proposing have not been sufficiently discussed. Therefore, despite previous efforts to describe the constellation of digital technologies applied throughout this chain, it is still unclear where these technologies are leading to, and what social, economic and environmental outcomes do they present. This article seeks to contribute to this discussion by answering two questions. First, what are the characteristics of digital technologies and how have they been applied to address the sustainability challenges of the CVC? Second, what socio-technical pathways are being promoted by such technologies and what social and environmental consequences do they represent?

In this paper we focus on the analysis of digital tools used in the first stage of the CVC designed to provide a) advisory services and b) market access to coffee producers. The analysis is framed by a socio-technical perspective, where technological transformations are understood as a configuration of multiple relationships between the social and the technical domains (Kilelu et al., 2013), and where it is recognized that the technical characteristics of artifacts are imbued with the quality to create certain social, economic and ecological contexts (Winner, 1980). Following this framework, we conducted an analysis of technical characteristics (functionality, technologies included, operation rules, information flow) of 20 digital tools identified through a review of secondary information, across three themes: 1) knowledge and value systems represented, 2) power structures, and 3) effective use. Through this analysis, different socio-technical pathways were identified, each one characterized by certain opportunities and challenges that can facilitate or constrain the achievement of sustainability objectives. With this identification we aim to contribute to the anticipation of potential impacts of digitalization, before lock-in dynamics preclude changing the course if necessary. Our empirical results also contribute to expanding the understanding of technology-society interactions within the framework of digital agriculture.

### **3.2. Coffee: sustainability challenges and innovation opportunities**

Coffee is produced predominantly by smallholder farmers (Rodrigues and Almeida, 2020; Lerner et al., 2021), living in more than 50 producing countries in the southern hemisphere (ICO, 2014). It is a labor intensive system (ICO, 2020), providing livelihoods for 25 million farmers (Grabs, 2017) and jobs for 125 million people in Latin America, Africa and Asia (Ramirez-Gomez et al., 2022). In the roasting and trade sector, on the other hand, a few big players dominate the market (Grabs, 2017; Grabs and Ponte, 2019).

This system is characterized by different paradoxes. First, coffee is produced in the South and consumed in the North. Second, although its production process is relatively straightforward (green coffee is roasted, grounded and steeped in water for consumption) (Grabs, 2017), the supply chain, is in reality, remarkably

complex. Third, coffee is a multi-billion dollar business in expansion (Sachs et al., 2019), with emerging added-value related to quality and sustainability (Daviron and Ponte, 2005), however, the majority of coffee producers, who are smallholders, remain in high levels of poverty (Voora et al., 2019, Lerner et al., 2021; Fromm, 2022). Fourth, all historically developed relations of production, processing, trade, and consumption, which are already highly sophisticated, could be disrupted by the effects of climate change (Läderach et al., 2017; Civera et al., 2019; Verburg et al., 2019).

### **3.2.1. Sustainability challenges for the coffee value chain**

Low and volatile coffee prices paid to growers (DeFries et al., 2017; Mehta and Chavas, 2008), precarious working conditions (DeFries et al., 2017), lack of access to capital (Sachs et al., 2019), and the effects of unpredictable and extreme weather patterns due to climate change (Läderach et al., 2017; Voora et al., 2019) constitute a peril for farmers' livelihoods, and place a great pressure on the value chain in relation to multiple United Nations (UN) Sustainable Development Goals (SDGs), such as # 1 - no poverty; # 10 - reduced inequalities; and # 13 - Climate action.

Low and volatile coffee prices can be mainly explained by a lack of participation and influence of farmers in a market dominated by powerful players, or by circumstances beyond their own control, such as changes in global production due to climate shocks in pivotal countries like Brazil or Vietnam. The market liberalization after the fall of the International Coffee Agreement (ICA) (1962-1989) strongly reduced the bargaining power of coffee producers (Talbot, 2004). In this process, the role of producers as price-takers was consolidated within a buyer-driven commodity chain (Ponte, 2002; Bitzer et al., 2008). This condition, added to information asymmetries between producers and traders (Samper and Quiñones-Ruiz, 2017), and an oligopolistic structure in the processor and retailer segments, facilitated opportunistic behavior and the practice of unfair trading practices (Lerner et al., 2021).

The coffee market has not remained static after liberalization. In the last decades, new markets focused on product differentiation and shorter chains, have emerged (Borrella et al., 2015; Grabs, 2017), together with a deconsolidation of the chain that came with the rise of new players in the processing and retailing segment (Grabs, 2017). However, in these new models, producers have maintained a minimal level of value appropriation, since they continue selling raw material in a market where the value related to material and symbolic (e.g. origin, sustainability) quality attributes is captured through the roasted coffee, the final beverage, and the experience of drinking in coffee shops (Daviron and Ponte, 2005; Quiñones-Ruiz, 2020). More recently, the market is experiencing a reconsolidation process, as the post-2008 economic recovery and a growing consumption of specialty coffee drew a favorable scenario for corporate merges to produce

a new generation of top roasters (Grabs, 2019). In consequence, despite the changing patterns, the general distribution of power remains remarkably similar to the situation in the 1990s (Grabs, 2017).

Parallel to a dynamic of power asymmetry distributed vertically throughout the chain (producers, traders, roasters, consumers), an asymmetry of power also occurs horizontally. The level of organization, production scale, and capital, vary within producers within and between coffee producing countries. While many smallholder farmers continue living in difficult conditions, with poor infrastructure, low access to education, and dependency on intermediaries, others have been able to bridge the information gap and connect with premium markets (Grabs, 2017), or establish large-scale plantations focused on production intensification (De Almeida and Zylbersztajn, 2017).

The environmental footprint of coffee productions is related to the crop's need for nutrients (often solved using synthetic fertilizers), the incidence of pests and diseases (often controlled using pesticides), the generation of waste, and the deforestation of land for crop expansion. The use of synthetic fertilizers and pesticides in coffee cultivation is associated with pollution of coffee ecosystems (Perfecto and Vandermeer, 2015), and synthetic fertilizers are an important source of greenhouse emissions (Rikxoor et al., 2014). Additionally, the system is highly vulnerable to the impact of climate change. The temperature increment and change of precipitation patterns as result of climate change has the potential to seriously affect coffee yields (Läderach et al., 2017; Verburg et al., 2019) and reduce the area suitable for cultivation (Bunn et al., 2014). Warmer temperatures increase the risk of pest and disease outbreaks (Ghini et al., 2011; Sachs, 2019).

### **3.2.2. The potential role of digital technologies in the sustainability of coffee**

Improving smallholder producers' conditions has been recognized as a priority to achieve the sustainability of the CVC (Grabs, 2017). This situation demands the transformation, not only of the technical processes within the coffee production system, but also of the forms of participation of producers in the chain. This is a process in which digital technologies can play a role through two relevant mechanisms: 1) facilitating knowledge exchange and social learning and 2) promoting participation of farmers in the value chain through enhanced visibility and coordination.

The use of digital technologies to exchange information, can contribute to improve agricultural practices with effects on productivity, production costs and risk management (Grabs, 2017). Additionally, information transmitted through digital channels can be used to learn about sustainable practices and actions for climate change adaptation (Sachs et al., 2019; ICO, 2020), and reduce information asymmetries that can lead to unfair trade practices (Civera et al., 2019; Lerner et al., 2021). Digital tools can provide relevant advice to deal with pest and diseases that affects coffee, such as coffee rust (*Hemileia vastatrix*), the leaf

coffee miner (*Leucoptera coffeina*) or the coffee berry borer (*Hypothenemus hampei*), and to more efficiently use of fertilizers and pesticides, thereby reducing environmental impacts and production costs derived from inefficient use (Barbedo 2013; Velásquez et al., 2020).

Participation of farmers in platforms such as digital marketplaces, blockchain or social networks, can improve their visibility and participation in the value chain, with effects over value distribution, intermediation and access to inputs. More direct trade through these platforms can contribute to coffee growers capturing a larger fraction of the retail price that currently only captures a 10% of the global coffee market (Panhuysen and Pierrot, 2018). These platforms can facilitate communication between farmers and actors placed at the lower end of the supply chain, procuring new possibilities for information exchange and mutual learning (Civera et al., 2019). These contributions have a strong potential given the complexity of the CVC, composed by a multitude of actors connected through multiple direct and indirect commercial and social relationships (Grabs, 2017; Rodrigues and Almeida, 2020).

Visibility and communication opportunities that arise through the action of digital technologies can link farmers with high-value coffee markets (ICO, 2020); capitalizing on the growth of this segment in the global coffee market (Grabs, 2017; Voora et al., 2019). Digital technologies can reduce transaction costs (Grabs, 2019; Lerner et al., 2021), and contracts can be facilitated by creating digital records (including past compliance) (ICO, 2020), and automatized enforcement (e.g. smart contracts). These possibilities represent a promising opportunity considering the high transactions costs of the CVC associated with a weak institutionality (ICO, 2020; Lerner et al., 2021). Additionally, digital records, trade platforms, and social networks, can facilitate access to services and products, such as credit, insurance, or agricultural inputs and machinery.

### **3.3. Analytical framework: socio-technical interactions in technological transformations**

The concept of socio-technical systems understands technology as a subsystem embedded in social relations (Hughes, 1987), where both domains (technical and social) continuously shape each other (Kilelu et al., 2013). The concept has been used by different authors like Geels (2004), Fielke et al. (2019) and Rijswijk et al. (2021), to analyze the interrelationships between the two domains, and the nexus between science, innovation and society (e.g. Leeuwis, 2004).

Technology is derived from, and reflects, particular socio-economic contexts, hence, it is socially constructed. It also shapes said contexts, including their political relationships (Winner, 1980). Links between technical and social systems relate to the representation and reproduction of certain knowledge and

value systems by the innovation processes (e.g. Wolf and Wood, 1997; Carbonell, 2016; Bronson, 2019; Klerkx and Rose, 2020; Lajoie-O'Malley et al., 2020), the distribution of power (e.g. Winner, 1980; Brey, 2008; Zheng et al., 2018; Seyedsayamdost and Vanderwal, 2020), or the role of technology in enabling or constraining human development (e.g. Zheng, 2009; Kleine et al., 2012; Kritikos, 2017; Manski and Manski, 2018; Poveda and Roberts, 2018; Rijswijk et al., 2021).

In this article, we collected these three elements to set the analytical framework to examine the process of digitalization in the CVC. We consider this approach to be appropriate, driven by the concept of socio-technical systems, considering that sustainability challenges of the CVC present a strong social and political component (see previous section). With this perspective, we identified three themes to structure our analysis: 1) knowledge and value systems represented, 2) power structures, and 3) effective use to produce change. We then linked these themes with the technical characteristics of artifacts (Figure 2).

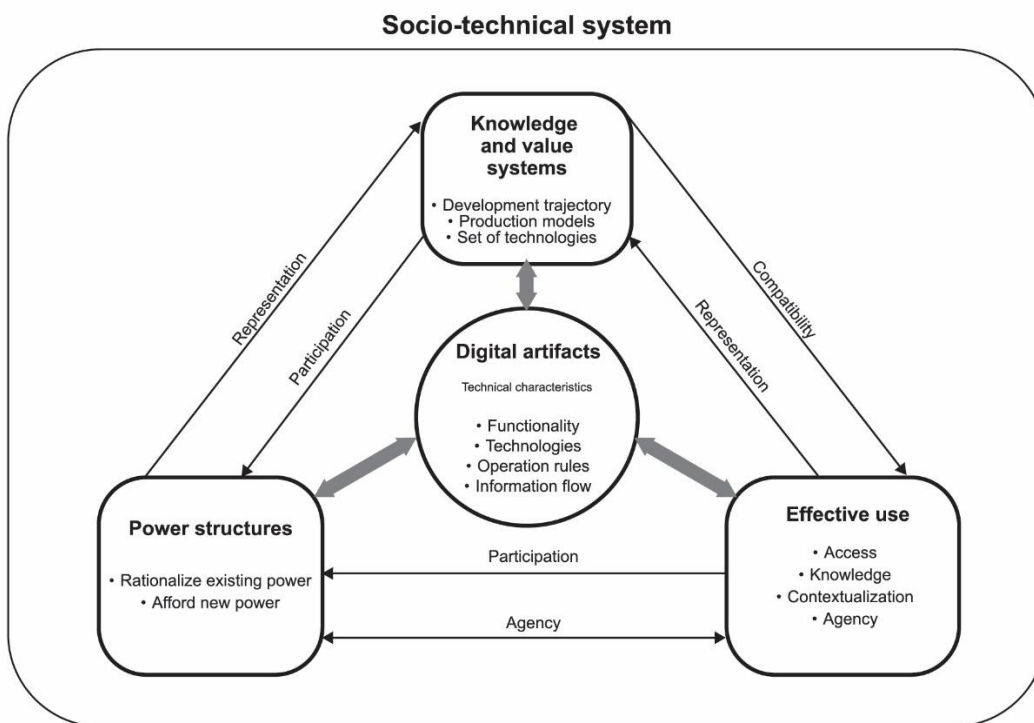


Figure 2 Components of the digital socio-technical system

### 3.3.1. Knowledge and value systems represented

Value systems guide innovation processes, and determine specific outcomes (Zheng et al., 2018; Bronson, 2019; Klerkx and Rose, 2020). For example, dreams and imaginings, influence innovations, which in turn,

shape human actions and future scenarios (Gidely, 2017). Depending on the knowledge and value systems where these dreams and imaginings are nested, different innovation pathways emerge, and different actions to address sustainability challenges are prescribed.

One of the ideas behind Kranzberg's first law of technology, "technology is neither good nor bad; nor is it neutral" (Kranzberg, 1986, p. 545), echoes the idea that the way technology is structured and applied in a given social context, determines specific trajectories that differ from other possibilities. Innovation pathways include certain technologies and socio-economic systems, while others are excluded (Carbonell, 2016; Schlaile et al., 2017; Pigford et al., 2018). In the context of digital agriculture, the types of innovations emerging can have fundamental implications on the agricultural production models promoted (or even allowed), and how the challenges of agricultural systems are addressed from a technical and political perspective. In the socio-technical system, when a hegemonic model and lock-in dynamics are consolidated (where exclusion makes it difficult to change the course towards other models), inequalities and centralization can emerge (Rotz et al., 2019), creating a conflict with sustainability goals (# 10-reduced inequalities).

Knowledge and value systems, often hegemonic, drive certain socio-technical trajectories, which envision the future of agriculture (see Lajoie-O'Malley et al., 2020), applying a specific set of technologies in the process. Complying with Kranzberg's third law of technology, "technology comes in packages, big and small" (Kranzberg, 1986, p. 549), digital agriculture is represented by a particular package of technologies (commonly associated with "high-tech", "disruptive", "game-changing" innovations), while other packages are left out. However, technology packages, less associated with "high-tech" (Stuiver, 2006), such as forms of ecological intensification, permaculture, and regenerative agriculture, can be harmonized, and are not necessarily incompatible with digital agriculture (Van Hulst et al., 2019). In turn, the type of technologies included determines the set of possibilities available to users, the flow of information, and the access and conditions necessary for its effective operation (compatibility and adaptation).

### **3.3.2. Power structures**

Technologies are means to distribute and exercise power in society (Winner, 1980; Marvin, 1988; Brey, 2008). Deliberately or not, societies are shaped by the technological systems they choose (Winner, 1980). In the decision-making regarding these technological systems (e.g. selection, operation, distribution), different actors hold different positions and different degrees of authority. Also, these innovation processes bring different consequences (some beneficial, some harmful) for the different actors (Winner, 1980; Stilgoe et al., 2013; Lajoie-O'Malley et al., 2020;), which, in turn, can shape hierarchical structures.

Technology can be used to rationalize existing power structures (Zheng and Stahl, 2011), or to generate new capacities for certain actors to exercise power over others (Brey, 2008). Winner (1980), suggests that technologies and their technical characteristics shape political systems and social dynamics (e.g. centralized or decentralized, egalitarian or inegalitarian, repressive or democratic). According to this, the way in which control over technologies is distributed by means of access, ownership, and technical, financial, and political capacity, creates certain power structures, where control grants the controller the capacity to use technologies for achieving specific goals. These can be for the benefit of the whole society or, on the contrary, for the benefit of particular groups. Similarly, control of technologies may be in the hands of a broad group of constituents, or may lie with only a small number of actors.

Literature suggest that digital agriculture will produce major shifts in power structures within agri-food chains (Wolfert et al., 2017). These types of changes include new forms of social coordination (Wolf and Wood, 1997), new roles and new actors (including cyber agents), and new patterns of information exchange. This can lead, for example, to new forms of negotiation, value distribution and learning processes.

### **3.3.3. Effective use to produce change**

The process of digitalization in agriculture is related to the gap between the technological haves and have nots (Rama and Wilkinson, 2013). This has important consequences for sustainable development. Diffusion of digital agriculture technologies and the dissimilar possibilities of access and use shape the creation of hierarchies (Rose et al., 2016; Pfeizer et al., 2020; Seyedsayamdost and Vanderwal, 2020). These hierarchies result, for example, in differentiated levels of agency between farmers and agri-business, or between rich and impoverished farmers (Bronson, 2019), and asymmetries in the distribution of costs and benefits derived from the use of these technologies (Rijswijk et al., 2021). This not only relates to differences of access to equipment, but also encompasses differentiated access to supporting infrastructure (e.g. internet and electricity) (Seyedsayamdost and Vanderwal, 2020), and to the knowledge and analytical capabilities necessary to operate the technologies and interpret the information (Kritikos, 2017).

Several factors determine whether information can be used effectively. Agriculture is a localized and context-specific activity. Therefore, contextualized information is required. General information, out of date, and framed into spatial and action scales outside the scope of users, has little value. Effective use of information is also influenced by the capacity of users to transform the structure and dynamics of the agricultural system, or to change practices following recommendations. In the case of farmers, this is related to the pre-existing levels of agency at farm and value chain level.

Access to devices and to the information alone does not improve people's wellbeing, if the possibility of using this opportunity to effectively change their lives is not present. This possibility or impossibility can be derived from the technology itself, or from the social and political structures in which the technology-individual interaction takes place. In this regard, development of specific individuals or groups is affected when technology cannot be used to achieve their own goals, while other individuals or groups can, or when a technological option that is presented to them is not compatible with their own needs and interests, and its use therefore, does not allow them to live the life they value (Kleine et al., 2012).

### **3.3.4. Technical characteristics**

Technical characteristics of artifacts inherently entail a political component, for example, determining compatibility with certain power structures and knowledge and value systems (Winner, 1980). Their operation, in turn, contributes to shaping those structures and reproducing said systems in a feedback loop. Additionally, the technical characteristics determine the possible affordances of each technology and the requirements to make said affordances effective (effective use).

In order to evaluate the role of digital technologies in the sustainability of the CVC, we integrate these ideas with the study of the previous three themes. To perform this analysis, we organized the technical characteristics of material and non-material digital tools into four categories, each with different attributes and working mechanisms: 1) functionality, 2) set of technologies applied, 3) operation rules, and 4) flow of information.

Functionality relates to the goal of the tool, that is the problem that it seeks to solve and the proposed way to do it. Different value systems consider different sets of problems as more or less relevant, which shapes the goals of digital tools, and also influence the proposed way of solving them. For example, under certain value systems, it is imperative to solve the problem of global hunger, however, the proposed way to solve it may vary (increase productivity or increase efficiency in food distribution). The orientation of the tools can have consequences on power structures, as functionality can favor certain groups, exclude others, or create opportunities for new types of relationships.

A digital tool may be composed of a single technology (e.g. SMS), or a set of technologies. Different types of value systems are identified with different sets of technologies (high-tech, low-tech or mixed systems). Values can be translated into the technologies through the decisions made during the design (e.g. programmers' values can be transferred to the software) (Rijswijk et al., 2021). The selection of technologies has consequences on power structures and effective use, as the way in which access possibilities are socially distributed, together with technology selection can create processes of empowerment or exclusion.

To operate effectively, digital tools require that particular conditions are met. These requirements can be described as rules of operation. Each digital tool has different rules of operation, which are determined by factors such as selected technologies, requirements of data, programming and communication, and the expected output. To meet these operating rules, specific technical, social and economic factors has to be addressed (e.g. technical skills, material conditions, information availability). There are “open” tools, where the conditions can be met by different groups of users (including marginalized communities), and “closed” tools, where only certain groups can meet the conditions. Some technologies can only operate in some systems (Winner, 1980). For example, certain forms of precision agriculture, using sensors and actuators “embodied” in large heavy tractors, may be more suitable to operate in large scale production (Carbonell, 2016).

Based on the technologies involved and the rules of operation, digital tools generate particular patterns of information flow, expressed in attributes such as direction (unidirectional, bidirectional, multidirectional), content (nature, quantity, context), and control. According to these attributes, certain knowledge systems and values can be represented and reproduced through the content. These attributes also contribute to define power structures through the distribution of access to information (symmetric or asymmetric), or the authority itself over this flow. This control is represented in the capacity to decide what information is collected, who participates, who has access to what, the way in which value is generated, and how this value is distributed.

## **3.4. Methods**

### **3.4.1. Identification of the tools**

In consideration of the sustainability challenges of the CVC (Section 2), the selection of tools included in the present analysis, is focused on two types of tools developed to produce an impact in the first stage of the coffee agrifood chain (farm to cooperative level): 1) tools for advisory services to promote knowledge exchange and learning, and 2) tools to promote access to markets, goods and services.

The goal of the first group is to provide technical assistance for the management of the farms. This through unidirectional or multidirectional communication systems, data bases or computer programs developed to identify problems and provide recommendations based on input data. These tools can enhance two-way communication, not only between farmers and other human actors, but also between farmers and computer programs, creating possibilities for tailored advice based on data collected from individual farms.

The second group is oriented to facilitate communication and coordination between producers and other actors downstream the value chain (e.g. roasters, traders, consumers), contributing to enhance farmers' visibility and participation. This includes tools linking farmers with global markets and facilitating on-line transactions (e.g. digital marketplaces), and tools to digitally record transactions and attributes of the product in its trajectory along the value chain (traceability systems).

We searched in several databases (Scopus, Science Direct, Springer, Scirus, ACM Digital Library, IEEE Xplore, Google, Google Scholar, FAO e-agriculture platform), using combinations of the following search terms: (i) coffee, (ii) digital, (iii) app, (iv) data, (v) smart, (vi) digital marketplace, (vii) digital extension, (viii) ICT, (ix) decision support system, and (x) network. The search was conducted in November 2020. Sources in English and Spanish were consulted. Reports from key informants included additional tools. The search revealed the existence of a diverse group of digital tools (mobile applications, web platforms, electronic sensors, Short Message Systems –SMS -, computer software) oriented to producers and cooperatives. After reviewing their functionality, a group of 20 tools corresponding to the two focus categories was identified (Table 4). All the tools included in this list are focused on coffee, except for the tools Agropad, Thuoc BVTV and Wefarm, that, which although cover a diverse array of crops, were included in the analysis because they were originally piloted in Coffee and then later expanded to other crops. Considering the dynamic nature of the process of digitalization in the CVC, this selection represents a snapshot of the available tools in the specific timeframe of our investigation. It is important to consider that new tools emerge every day). Tools whose information was only in the languages of relevant producing countries (e.g. Portuguese and Vietnamese), may have been excluded. Nonetheless, the search criteria yielded tools with a global distribution.

### **3.4.2. Data collection and analysis**

In depth information on the technical functionalities of these 20 tools was gathered through the review of additional secondary information retrieved from internet and direct information from on-line interviews with key informants. In total 101, internet sources were consulted (organization's web pages [57], web news [27], institutional reports [7], apps [4], papers in journals [3], a digital brochure [1], conference presentations [1], and a podcast [1]). 15 semi-structured interviews selected through purposive sampling were carried out between December 2020 and May 2021. Interviewees included 13 developers and two researchers. The interview guide included questions on the background of the respondent, and the tool development process, functionality, and targeted users. The interviews were recorded and recordings were transcribed and analyzed in the light of the three identified themes: knowledge and value systems represented, power structures, and effective use.

Table 4 Overview of digital tools for the first mile of the coffee value chain

Category	Name	Targeted users	Focus areas	Developer	Sector	Countries
Advisory services	Agenda Cafetera	Farmers; technicians	Planning. Pest and disease management	Buxtar	Startup	Colombia; Peru
	Agrocloud	Farmers	Pest and disease management	University of Cauca	Research	Colombia
	Agropad	Farmers; technicians	Soil management	Enveritas; IBM	NGO; Corporative	Brazil; Uganda
	CPEST	Farmers	Pest and disease management	Georgia Southern University; University of the West Indies; Virginia Commonwealth University	Research	Jamaica
	Coffee Cloud	Farmers; technicians	Planning. Pest and disease management	Center for Digital Acceleration (DAI); Centro Clima consortium; Anacafe; Icafe	Corporative; Research; Cooperative	Central America
	Coffee Krishi Taranga	Farmers	Market information. General agricultural practices	Central Coffee Research Institute (CCRI); Coffee Board of India; Precision Agriculture Department (PAD).	Research; Government	India
	COVIR 2020	Farmers	General agricultural practices; Networking	Bean Voyage	Corporative	Costa Rica
	Cromai	Farmers	Quality control	Cromai	Corporative	Brazil
	Cropster	Farmers; cooperatives; roasters	Quality control	Cropster	Corporative	Global
	GREENcoffee	Farmers	Planning. Market information. General agricultural practices	GREENcoffee consortium	Research; NGO; Corporative; Government	Vietnam
	Kaapi Soil Health Monitoring and Management	Farmers	Soil management	Central Coffee Research Institute (CCRI); Indian Institute of Information Technology and Management -Kerala (IIITM-K)	Research	India
	Mejor suelo, mejor café	Farmers	Soil management	Anacafe	Cooperative	Guatemala
	My Crop Care	Farmers	Soil management. Water management	Rainforest Alliance; Smartfarming	NGO; Startup	India
	Thuoc BTVV	Farmers	Pest and disease management	IDH Sustainable Trade Initiative; Vietnamese Ministry of Agriculture and Rural Development	NGO; Government	Vietnam

Category	Name	Targeted users	Focus areas	Developer	Sector	Countries
	Wefarm	Farmers	General agricultural practices; Market information; Networking	Wefarm	Startup	Kenya; Uganda; Tanzania
	Algrano	Farmers; cooperatives; roasters	Coordination	Algrano	Startup	Global
	ifinca	Farmers; cooperatives; traders; roasters; consumers	Traceability. Coordination	iFinca	Startup	Global
<b>Access to markets, goods and services</b>	Farmer connect + Thank my farmer	Farmers; cooperatives; traders; roasters; consumers	Traceability. Coordination	Farmer Connect	Startup	Global
	beyco	Farmers; cooperatives; traders; roasters	Traceability. Coordination	Progreso Foundation	NGO	Global
	Fantine	Farmers; cooperatives; traders; roasters; consumers	Traceability. Coordination	Fantine	Startup	Colombia

### 3.5. Results

#### 3.5.1. Knowledge and value systems. What's in, what's out

The description of the functionality of the different advisory services and the identification of the content of information that is disseminated (Table 5), suggests that such tools are mainly rationalizing a productivist perspective concerning sustainability challenges. The orientation of these challenges represented by the functionality of the different tools, shows that poverty is mainly perceived as a problem of inefficient production, which can therefore be addressed by increasing productivity and reducing production costs. The ways of achieving these objectives vary, however, according to the focus areas (Table 4); the efficient use of inputs such as pesticides and fertilizers is predominant. This productivist approach is not perceived in opposition to conservation goals, in fact, the reduction of the environmental footprint, thanks to higher input use efficiency, is used to rationalize this perspective.

Table 5 Technical characteristics of tools for advisory services

Name	Functionality	Technologies	Operation rules	Information flow
Agenda Cafetera	Productivity Production costs Environmental footprint	Artificial Intelligence (AI) Smartphone	Expert system <sup>5</sup>	Tailored advice Conventional production (chemical inputs included). From tool to farmer
Agrocloud	Productivity Production costs Environmental footprint	Satellites AI Smartphone	Expert system	Tailored advice Conventional production From tool to farmer
Agropad	Productivity Production costs Environmental footprint	Microfluidics chip AI Smartphone	Expert system	Tailored advice Conventional production From tool to farmer
CPEST	Productivity Production costs Environmental footprint	AI Computer	Expert system	Tailored advice Conventional and non conventional production (biological and physical control) From tool to farmer
Coffee Cloud	Productivity Production costs Environmental footprint	Satellites Smartphone	Expert system Message service <sup>6</sup>	Tailored advice Conventional production From tool to farmer From extension agent to farmer
Coffee Krishi Taranga	Productivity Production costs Market trends Environmental footprint	Call center Mobile phone	Phone service <sup>7</sup> Message service	General information Tailored advice Conventional and non conventional production From tool to farmer From extension agent to farmer
COVIR 2020	Productivity Visibility Environmental footprint	Whatsapp	Social Network <sup>8</sup>	General information Conventional and non conventional production Multidirectional

<sup>5</sup> Field data is recorded; a computer model uses embedded expert knowledge as base to analyze recorded data; the computer model provide recommendations based on the analysis.

<sup>6</sup> Data is entered in a system to transmit messages; messages are transmitted to the receiver through her or his cellphone.

<sup>7</sup> User makes a phone call; a digital system receives the phone call and connect the user with technical staff, or transmit and record a voice message.

<sup>8</sup> Users register in a digital platform; the platform allows multidirectional message exchange between registered users (text, voice, pictures, videos).

Name	Functionality	Technologies	Operation rules	Information flow
Cromai	Quality	Sensors AI	Environmental monitoring system <sup>9</sup>	Specific conditions Conventional and non conventional production From tool to farmer
Cropster	Quality	Sensors	Environmental monitoring system	Specific conditions Conventional and non conventional production From tool to farmer
GREENcoffee	Productivity Production costs Market trends Environmental footprint	Mobile phone	Message service	General information Conventional and non conventional production From tool to farmer
Kaapi Soil Health Monitoring And Management	Productivity Production costs Environmental footprint	Google maps Geo-tagging Smartphone	Expert system	Tailored advice Conventional production From tool to farmer
Mejor suelo, mejor café	Productivity Production costs Environmental footprint	Smartphone	Message service	Tailored advice Conventional production From tool to farmer
My Crop Care	Productivity Production costs Environmental footprint	Computer model Smartphone	Expert system	Tailored advice Conventional production From tool to farmer
Thuoc BVTV	Productivity Production costs Environmental footprint	Web development Smartphone	Database <sup>10</sup>	General information Conventional production From tool to farmer
Wefarm	Productivity Visibility Environmental footprint	AI Mobile phone	Social network	Tailored advice Conventional and non conventional production Multidirectional

This focus on conventional production is especially prominent in models based on Expert Systems (ES), therefore, the knowledge base embedded in these tools favors management strategies based on synthetic inputs. Tools that provide generic information (message services), or human-human interactions (call services, social networks), can include other types of practices (not completely alternative systems). However, they never exclude conventional models. On the other hand, the functionality and content of such

<sup>9</sup> Digital sensors are used to measure environmental parameters; measures are converted into digital signals; signals are translated into information that can be interpreted by different actuators or the users.

<sup>10</sup> A digital library is created with technical information that is stored in a web location; users connect to the location, navigate and access the recorded information.

tools are overlooking alternative models such as organic production, permaculture, regenerative or climate-smart agriculture, agroforestry, or the possibility of enhancing farmers' agency through training in financial management.

In general terms, despite the new communication channels and information transmission possibilities, the direction of the information flow (predominantly from tool or from extension agent to farmer) (Information flow, Table 5) evidences that farmers continue to be perceived only as recipients of agricultural information. Linear, top-down diffusion models, centralized in closed knowledge systems settled in research centers and teams of "experts" dominate the landscape of digital advisory tools (the social networks COVIR 2020 and Wefarm are the only exceptions to this dynamic). In close relation to knowledge and value systems theme, this situation determines that mathematical models, computer programs and digital content, privilege the vision shared by these central authorities, at the expense of other, less hegemonic, perspectives.

The functionality of tools focused on promoting access to markets, goods and services (Table 6), shows that CVC challenges, such as low farm gate prices, value capture at downstream stages and lack of access to capital, are perceived to be related to farmer's low participation and lack of influence in the chain. It is envisioned that farmers' participation can be improved through disintermediation, improved coordination, and greater visibility. This is achieved through facilitated communication between producers and buyers (roasters, traders, and consumers), or between producers and financial service providers. These tools focus more on a model where the most important feature is that interested parties know each other, at least online (relational model). These types of systems tend to favor quality attributes over productivity. They are compatible with niche markets where coffee is traded as a differentiated product, associated with higher farm gate prices, and the application of high-tech technologies, especially blockchain. Advisory tools related to quality improvement (Cropster, Cromai), that also make use of high-tech solutions (environmental sensors, AI) are associated with these same markets.

Table 6 Technical characteristics of tools to promote access to markets, goods and services

Name	Functionality	Technologies	Operation rules	Information flow
Algrano	Dissintermediation Coordination Visibility	Web development Smartphone E-payment	Digital marketplace <sup>11</sup>	Origin information Farm gate price Participants identity From producers towards roasters
ifinca	Dissintermediation Coordination Visibility	Private blockchain Quick Response Coding (QR). Smartphone E-payment	Traceability system <sup>12</sup>	Origin information Farm gate price Participants identity From producers towards consumers
Farmer connect + Thank my farmer	Coordination Visibility	Private blockchain QR coding Smartphone E-payment	Traceability system	Origin information Social projects in source areas Farm gate price Geographical trajectory Participants identity From producers towards consumers
beyco	Dissintermediation Coordination Visibility	Private blockchain QR coding Smartphone E-payment	Traceability system	Origin information Participants identity From producers towards roasters, traders and financial organizations
Fantine	Dissintermediation Coordination Visibility	Private blockchain IA Smartphone E-payment	Traceability system	Origin information Farm gate price Participants identity From producers towards roasters and traders

### 3.5.2. Power structures. What changes and what doesn't

Tools for advisory services create new communication channels (human-human and human-program). Functionality of these tools evidences that the dissemination of knowledge, facilitates, in principle, learning

<sup>11</sup> Users register in a web-based platform and record information that can be consulted by other users; communication is established between users; the platform keeps record of these communications.

<sup>12</sup> A digital systems record attributes and relationships of a traceable unit (e.g. a batch of coffee) each time a change to these attributes and relationships occurs; the records are connected sequentially by the system; the sequence of records is transmitted.

processes and informed decision-making for all types of producers (small, medium, and large). The characterization of the information flow shows that social networks, such as COVIR 2020 and Wefarm, offer the possibility for multi-directional communication, and the option for farmers to have a more active role in the creation and dissemination of knowledge. Tools such as ES or environmental monitoring systems, create new power dynamics. Here, non-human agents (algorithms, mathematical models, sensors) act as creators and spreaders of agricultural information. Additionally, they drive decision making in the farms through technical recommendations, alerts that trigger certain actions, and forms of representing information. This, in turn, designates a new kind of agency to these technologies.

Digital platforms and traceability systems enhance farmer's visibility and coordination within the value chain. Through these systems, producers can communicate the attributes of their coffee and use it for advertising. Some tools allow the recording of transactions that can be shared with commercial partners, consumers or be presented to third parties, such as financial institutions, to establish credibility. For example, the platform Beyco is not only oriented to connect coffee sellers and buyers worldwide, but also to facilitate the record of online contracts that can be easily shared with credit institutions, this way creating new opportunities to access financial resources. The opportunities offered by secure traceability technologies, such as blockchain, have present the potential to link coffee prices to quality and sustainability attributes, as well as production costs<sup>13</sup> These technologies could thereby, theoretically, allow to attain higher farm gate prices, and processes of disintermediation, which can allow farmers to capture more value.

The descriptions from the interviews regarding the different networks of participants in development processes (Developer and Sector, Table 4), show that the digital socio-technical system is a space for the participation of new actors, such as start-ups like Algrano, Buxtar, Farmer Connect, Fantine, iFinca, Smartfarming, and Wefarm, and non-consolidated corporative actors such as Bean Voyage, Center of Digital Acceleration or Cromai. On the other hand, there are noticeably few agri-tech corporations in this constellation, despite the fact that Bayer-Monsanto, John Deere, Dupont, Syngenta, and DOW are traditional protagonists in the development and diffusion of digital technologies for agriculture. The participation of start-ups and organizations from the technological sector, including software and cloud service providers, have a central place in the development and operation of the tools. In turn, these non-traditional participants, are getting relevant influence in the trajectory of innovation. This includes decisions on the forms of participation of other actors (including farmers), the control of data, and the way value is created and distributed. More traditional players (roasters, research centers, government institutions, NGOs), acquire new roles and decision-making capacity, acting as developers of these technologies, financiers, or creators

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<sup>13</sup> Fantine uses a price index that includes cost factors such as production model, status of the plantation, management qualities (control of pests and diseases, fertilization, processing methods), and labor (quantity).

of digital content. All the while, according to the interviews, the participation of cooperatives and growers in the process of development has been marginal, and its inclusion has remained at the level of information collection and prototype testing, but not of the decision making. Also, there is evidence that the constellation of tools oriented to facilitate access to the market and financial services is dominated by start-ups (Table 4), making of these entrants, important new players in the way coffee trade is organized through digital channels, and key actors in the selection of the technologies to perform these operations.

The use of “high-techs” for recording and analyzing information (AI, sensors, blockchain), allocates authority to the actors who have access to these technologies, programming capacity and analytical skills. Blockchain technology, for example, can be implemented under different architectures (public or private). Public blockchains are platforms that any internet user can access. On the other hand, a permissioned (private) blockchain means that only authorized (registered) users can participate (Hald and Kinra, 2019). A permissioned blockchain, therefore, requires the existence of a central authority to set the rules and allow its operation. All the traceability systems analyzed are permissioned blockchains.

In theory, both groups of tools are aimed at solving problems common to all types of producers. In practice, however, differentiated access to technologies, required skills, and context compatible with operation rules (effective use), can deepen existing processes of hierarchization and exclusion, since already marginalized producers will find it more difficult to fulfill the requirements. On the other hand, already privileged producers (savvy, well informed, capitalized, with access to connectivity, oriented towards differentiated production in niche markets), have more chances of making use of these tools and obtaining the benefits.

Unlike advisory systems, which present a flow of information from human and cyber “experts” to farmers, in digital marketplaces and traceability platforms, information flows unidirectionally from farmers to downstream actors (Table 6). Despite the new possibilities of visibility and coordination, the information asymmetry remains unresolved. Currently, producers provide large amounts of specific information (location, industrial processes, sustainability indicators, and sale price), however, they do not receive similar levels of information in return from the other actors. Moreover, the market remains buyer-driven. Producers are a large and dispersed group that must compete with each other in online platforms to access a small and consolidating number of buyers. Likewise, they continue to sell a raw product, while value related to quality attributes continues to be captured mainly at the roasting and consumption stage.

### **3.5.3. Effective use. For whom the tech tolls**

Some tools make use of simple technologies (SMS, phone calls), as a strategy to reach a larger group of producers, however, these technologies offer less tailored advice than systems using AI, modelling, or

sensors, which may result in decontextualized information. Wefarm is an exception to this pattern, combining a simple system (SMS), with a "high-tech" system (machine learning), to connect farmers according to their specific information requirements and expertise, in order to open opportunities for tailored advice using a simple communication channel.

Smartphones apps are the most common form of user interface due to their possibilities of information management, interconnectivity, portability, and potential to present different types of information. However, this technology presents more access restrictions for smallholders than mobile phones due to the cost of devices, more complex operation and connectivity requirements. Digital marketplaces and traceability systems using blockchain technology require technical skills and connectivity to navigate; therefore, not all farmers have equal opportunities to participate. An exploration of participants of these platforms, shows that individual producers participating in these platforms tend to have a business profile, manage their own digital channels (web page, social networks), and show certain levels of sophistication, simultaneously offering coffee produced under different processes (washed, natural, honey) and mainly growing Arabica varieties oriented towards cup quality. Besides these more entrepreneurial individual farmers, cooperatives and NGOs are able to engage smallholder producers in these markets. Tools related to quality assurance (Cropster and Cromai), use environmental sensors, which can be expensive for smallholders. For their calibration, these systems require specialized knowledge (e.g. environmental thresholds for drying and storing coffee), and a specific infrastructure (specialized drying and storage infrastructure or roads between plots for the transit of vehicles carrying sensors). In this case, the selected technologies and the operating rules favor the group of producers with better infrastructure conditions and technical knowledge.

Considering that most advisory tools are focused on productivity in conventional systems, agroecological farmers would find these tools of little use. This orientation is especially marked in ES, therefore, this type of farmers would be excluded from using these tools and benefiting from the analysis capabilities of technologies such as AI and mathematical models.

On the one hand, advisory tools deliver market information to reduce information asymmetry and allow farmers to make better trading decisions. However, this information is not very useful for farmers who are restricted to local and few trading channels. On the other hand, digital marketplaces and traceability systems disclose farm gate prices with buyers (roasters, traders, consumers) as a transparency mechanism to push for a fair trade. This indicator of fairness could be difficult to interpret for consumers who might not understand the structure of the market and the conditions of production, and therefore could not know what a fair price would be. Moreover, these platforms continue to operate under a buyer-driven model, where producers have little influence on prices, beyond translating product attributes into advertising narratives.

This taking place in a highly competitive scenario, with a large number of producers and a more concentrated, better informed, and better connected group of buyers.

### **3.5.4. Opportunities and challenges for sustainability**

The analysis of the technical characteristics of the different tools allowed to identify the prevalence of a specific approach towards sustainability in each group of tools. This situation, in turn, suggest that there are two predominant digitalization pathways that are being proposed. On the one hand, advisory systems are promoting a productivist approach, focused on conventional production and efficient use of synthetic inputs. On the other hand, digital marketplaces and traceability systems are promoting a relational model, based on the establishment of communication and coordination between producers and buyers, shorter chains, and processes of differentiation.

Several sustainability goals are affected by these two pathways. In the first pathway, the reduction of knowledge asymmetries holds a central place, therefore, it is associated to facilitated access to agricultural knowledge through the diffusion of information in digital channels. Here, poverty is perceived mainly as a problem of inefficient production, therefore the central approach of these services is to provide information to optimize farm management to increase productivity, while reducing production costs and environmental footprint. These potential contributions to sustainability, however, are hindered by several challenges. A narrow perspective of development trajectories and agricultural models is overlooking structural causes of unsustainability (e.g. prevailing poverty in the producing sector) that fall out of the scope of productivity and efficiency goals. Neglecting alternative agricultural models precludes processes of harmonization between potentially complementary technologies (e.g. expert systems and regenerative agriculture), or the diffusion of climate change mitigation and adaptation practices. The linear, top-down model of information exchange that characterizes these tools and the digital gap persist as important challenges that prevent the effective use of these tools, and a more horizontal distribution of power within the value chain. Processes of social hierarchization can be promoted, in association with different levels of access, literacy, and agency between social groups (e.g. researchers, extension agents, smallholder growers, and industrial growers) (Table 7).

Table 7 Advisory services: opportunities and challenges for sustainability

Themes	Sustainability challenges				
	Poverty	Knowledge asymmetries	Reduced productivity	Environmental footprint	Climate change
Knowledge and value systems represented	Optimized farm management and coffee quality.		Optimize productivity.	Efficient use of synthetic inputs.	Reduced carbon footprint related to fertilizers.
	Overlook structural causes of poverty.	Limited diversity in knowledge from different production models.		Over-emphasis in conventional-industrial production. Overlook agroecological models.	Overlook mitigation and adaptation practices.
Power structures	Increased productivity and quality, and reduced production costs.	Informed decision making.			
	Digital gap creates hierarchies.	Linear top-down extension model.			
Effective use	Information oriented to optimize production process.	Tailored advice based on farm characteristics.	Agricultural practices to increase productivity.	More efficient use of synthetic inputs.	Availability of weather information.
	Reduced capacity to follow recommendations.	Digital gap hinder symmetric access to information.	Reduced capacity to follow recommendations.	Lack of knowledge regarding agroecological practices.	Lack of knowledge regarding mitigation and adaptation practices.

Digital marketplaces and traceability systems also propose mechanisms to improve the sustainability of the CVC, although from a different perspective (Table 8). The approach of this pathway is not focused on promoting specific agricultural practices, but on improving farmers’ participation through enhanced visibility and transparency. Given that these platforms are not necessarily linked to a productionist perspective, but are associated with a relational model (where the most important aspect is that interested parties know each other and cooperate), different production models can be represented. This “relational” pathway is linked with differentiated markets, where coffee attributes such as origin, quality, and compliance with socially and environmentally sustainable production standards are valued. Several challenges of this pathway, however, preclude a more effective contribution to sustainability goals. For example, enhanced participation in the market does not necessarily affect asymmetrical value distribution, as the points where the main value of coffee is captured remain outside the production stage. The linear flow of information that also takes place in this model, prevents farmers from getting valuable information from downstream stages, which is, yet, available for actors such as roasters, traders and consumers. Higher technical requirements of these systems make them exclusive and prevents the participation of marginalized producers. Although environmental friendly practices are included as part of the certifications with which the coffee is marketed, this attribute must compete with other quality attributes not related to the environmental dimension. Sustainable production, therefore, does not have a central role, and there are not further monitoring schemes beyond the labels used in advertising, making it difficult to grasp the contribution in terms of environmental protection.

Table 8 Digital marketplaces and traceability systems: opportunities and challenges for sustainability

Themes	Sustainability challenges				
	Poverty	Knowledge asymmetries	Reduced productivity	Environmental footprint	Climate change
Knowledge and value systems represented	Access to markets, credits and donations.	Diversity of production models.		Sustainability practices are a valued attribute.	Climate friendly production is a valued attribute.
				Sustainable production compete with other attributes (e.g. origin, quality, direct trade).	Climate friendly production compete with other attributes (e.g. origin, quality, direct-trade).
Power structures	Increased farmer's visibility.	Value chain transparency.			
	Value distribution remains unaltered.	Unidirectional flow from producers towards downstream actors.			
Effective use	Enhanced communication of production attributes and financial records.		Access to capital (credit, donations) to invest in production.		
	Digital gap and competition reduces effectiveness.	Lack of information from downstream stages to make decisions in production.	Digital gap hinder access for marginalized producers.		

### 3.6. Discussion

The identified pathways are consistent with previous conceptualizations and findings from the broader literature in the area of critical studies of digital agriculture, and with the analysis of current power dynamics within the CVC. The way in which these pathways manifest different socio-technical dynamics presented in the literature, however, speaks to relevant differences that have to be accounted for, to better understand the outcomes of these pathways to sustainability.

#### 3.6.1. Advisory services. More productivity for a commodity market

The association between digital tools for advisory services and productivist perspectives is not surprising. Several studies found that digitalization in agriculture rationalizes a production model dependent on chemical inputs (Wolf and Wood, 1997; Fraser, 2019; Clapp and Ruder, 2020). It has been argued that digital agriculture is associated with techno-centric and productivist perspectives, focusing on technical fixes to maximize production and higher input use efficiency, as the main mechanisms for solving global challenges, including hunger, poverty and environmental footprint (Bronson, 2018; Rotz et al., 2019; Kuch et al., 2020; Lajoie-O'Malley et al., 2020). While such tools may enable a more efficient use of agrochemicals, they do not present alternatives and do not enable systemic changes related to agroecological models. Despite the generally strong interest of the coffee industry to adapt to climate change (Sachs et al., 2019), the tools analyzed largely neglect adaptation and mitigation practices beyond efficient use of

fertilizers – while legitimizing the use of these products that generate large volumes of greenhouse emissions. Continuing along this trajectory would promote a technological lock-in, where hegemonic knowledge and value systems acquire outstanding representation thanks to centralized pre-existing power structures. Critical assessments of digital agriculture have already warned about the risk of this dynamic, and about the association of digitalization with dominant techno-economic forces and reinforcing cycles (Hellström, 2003; Clapp and Ruder, 2020).

The linear, top-down model of information dissemination, predominating in advisory systems, contributes to this lock-in dynamic. Digital technologies would only be optimizing conventional extension dynamics and cementing the already established roles, with researchers and practitioners as experts and content generators, and producers as information recipients. Social networks may constitute alternatives to this unidirectional model because they distribute the role of knowledge creation, allowing producers to also play this role, making these networks, more inclusive systems. According to our scan, however, these platforms are not the prevalent model.

The use of technologies such as AI or computer models for the analysis of information offers new possibilities to generate tailored advice. At the same time, they represent a change in power structures, related to the action of algorithms and computer programs, and their capacity to influence human behavior. Lustig and Nardi (2015) coined the term "algorithmic authority", expressed as "the trust in algorithms to direct human action and to verify information, in place of trusting or preferring human authority" (p. 743). Coffee producers that rely on ES for the farm management, are subject to the newly acquired agency of algorithms. While there are opportunities made accessible by automated and contextualized recommendations, the use of such technologies can also cause producers to lose the ability to interpret the elements of their farm (weather, plants, animals, soil) and to take decisions autonomously (Carolan, 2018; Rotz et al., 2019). Furthermore, certain values can be transferred to these systems through programming, including biases and preferences, that can result in exclusion processes (Rijswijk et al., 2021), for example, the observed bias towards conventional production.

Simple technologies have greater possibilities of reaching a broad number of smallholder producers, however, the possibilities of providing tailored advice are reduced. More sophisticated technologies, applying automated analysis systems (sensors, AI, modeling) generate more specific information, however, they present greater accessibility barriers. As such, already marginalized smallholder producers are compelled to receive generic information, while better-off producers with greater material possibilities and digital literacy benefit from tailored advice. In this case, the gap between smallholders and more capitalized farmers, produced by the asymmetrical access to digital technologies, is creating hierarchies of knowledge.

In many coffee-growing areas in the Global South, connectivity is still limited (Seyedsayamdost and Vanderwal, 2020), and the costs of smartphones remain prohibitive for many smallholder producers (Rama and Wilkinson, 2013). However, broadband internet is expanding, mobile connectivity improving, and smartphone costs are declining (FAO, 2013; Emeana et al., 2020). This can improve the accessibility of these technologies in the future. In certain contexts, farmers accessing such technologies may still struggle to make effective use of the information and implement the technical recommendations. In interviews with coffee producers in Brazil and Colombia, respondents expressed that access to digital information is not a major problem, but there are many social, cultural, and financial obstacles to implementing the recommendations (Ramirez-Gomez et al., 2022). The case of environmental monitoring systems based on the action of automatic sensors exemplifies this condition. The infrastructure requirements, technical knowledge, and equipment costs, make these tools, systems of exclusion for smallholder producers. They would then be compelled to receive technical recommendations to increase the production of coffee under a conventional system, to be sold in commodity markets, even if they aspire to participate in other types of models.

### **3.6.2. High-techs to participate in markets**

Given its possibilities to perform end-to end traceability, blockchain technology has been metaphorically described as an "information lighthouse" (Hald and Kinra, 2019, p. 390). Correspondingly, the traceability possibilities of blockchain are explored by the tools oriented to promote access to markets, goods, and services. The rationale is that this technology, together with the participation of producers in digital marketplaces, increases their visibility and facilitates coordination with buyers (roasters, traders, consumers).

Together with environmental sensor systems, the operating rules and the set of applied technologies of these platforms, mean that such systems rely heavily on high-tech solutions, with high entry barriers for smallholder producers. Therefore, this model favors producers with greater financial and technical capacities, and with the opportunity to participate in the relational model, which is oriented to differentiated markets with added value. It is salient that individual producers participating in these platforms have a more business oriented profile. However, cooperatives and NGOs, can bridge this gap and reduce the process of exclusion. These organizations are currently coordinating groups of small producers, helping them to bridge the technical and knowledge gap. This allows smallholder producers to participate, at least indirectly. This same role as supporting institutions has been previously described in relation to facilitation of extension services (Fromm, 2022), participation in direct trade schemes (Grabs, 2017), and processes of certification in sustainability standards (Birkenberg and Birner, 2018; Ramirez-Gomez et al., 2022).

Participation in a relational model, however, does not necessarily translate into a substantial improvement in the conditions of producers. The persisting information and value distribution asymmetries, and the processes of power recentralization in the hands of the new technology controllers are factors that can prevent more substantive changes to power imbalances within the CVC. This chain is characterized by asymmetry of information (Civera et al., 2019), and powerful players, such as roasters and traders, use this disparity as a competitive advantage, engaging in opportunistic behaviors (Lerner et al., 2021), and interpreting the market to develop adaptive responses. On the other hand, information related to consumer preferences at local and global scales can help farmers to make decisions oriented towards a more effective market participation (Maru, 2013). Additionally, the availability of price information from downstream stages (e.g. traders, roasters, shops) could enable fairer commercial relationships and reduce asymmetries because of increased transparency and mutual scrutiny. However, despite the opportunities for a multidirectional, transparent, and secure flow of information, especially through technologies such as blockchain, this information is not currently disclosed. The pattern seen in the analyzed tools is a unidirectional flow, from farmers to downstream actors. Therefore, the information asymmetry is not only maintained, it may be exacerbated due to increased volumes of information made available to those actors who are already better informed.

Despite increased visibility, within digital marketplaces and traceability systems, the value related to quality attributes continues to be captured mainly at the roasting and consumption stage. The “coffee paradox” (Daviron and Ponte, 2005) is the process of coexistence of a coffee boom, related to new consumption patterns (specialty, fair trade and sustainable coffee), with a coffee crisis in the producing sector. The occurrence of this paradox is possible because powerful players in the processing and trade sector can capture the value created at origin, using effective marketing strategies, such as targeted communications with the segment of aspirational consumers (e.g. direct trade, fair trade, sustainability labels), attractive packaging (now including QR codes), and the design of drinking experiences. In this regard, the coffee paradox persists in digital platforms. Meanwhile, producers continue selling raw materials, while they continue without participating in the activities where the value is captured, and without having decision possibilities on the way quality attributes are defined. Moreover, the marketplace is becoming crowded with similar narratives about the attributes and story of the coffee and the farmers (Sachs et al., 2019), contributing to create a process of re-commoditization, in a context of high dispersion in the producing sector and recentralization of the processing and trading sectors (Grabs and Ponte, 2019).

Based on their communication possibilities, digital marketplaces and traceability systems present the opportunity to reduce coffee price abstraction (sold as a commodity in the futures market), linking coffee prices with the physical product (e.g. quality attributes, production costs, agricultural practices). During the

2017 World Coffee Producers' Forum, much of the discussion centered on the need to investigate price and cost trends, along with the instauration of a sustainable minimum price (Grabs and Ponte, 2019). Similar initiatives are the calculation of the "True Price" (True Price, 2017), or the Return to Origin (RTO), described as the percentage of coffee retail sales that goes back to the coffee supply chain at its origin (Transparent Trade, n.d.). To procure better prices, digital platforms can align with these initiatives and include these kind of calculations to set the price (at least as a floor). This will require, however, the good will of players who are currently favored by the current system.

Because of the coordination possibilities they present, digital marketplaces and traceability systems are promoted as a mechanism to achieve a shorter chain, directly connecting producers with buyers. Additionally, blockchain has been described as a technology that can facilitate disintermediation given the possibilities of decentralized peer-to-peer verification. In practice, however, traceability systems evaluated in this study are mostly built on proprietary and private blockchains, therefore, the power to coordinate remains in the hands of central authorities. This is leading to a recentralization process, through the substitution of traditional intermediaries (brokers, aggregators, financial institutions) with new intermediaries (startups, tech-savvy entrepreneurs). These new actors define how farmers participate and how the benefits are distributed (Veen, 2021). The risk is that the control of digital infrastructures can be a form to exert power based on technological authority rather than a force of democratic participation for collective interest (Ertz and Arsenault, 2019). Digital marketplaces also act as intermediaries with relevant authority. They decide which actors can participate, and they coordinate the shipping (a charge for producers is included). For these reasons, in reality, the chain has not really become shorter, rather, the chain became more efficient. Whether this new efficiency translates into benefits for farmers, or profits for new intermediaries, largely depends on the rules under which the platforms operate, including producer's representation and participation mechanisms.

In environmental terms, the contribution of the relational pathway is not straightforward, and is difficult to generalize. As has been expressed, this model is associated with differentiated coffees for niche markets, which are commonly produced under certified sustainability standards. Although these certifications can play a positive role in the reduction of the ecological footprint of production by the inclusion of environmentally friendly agricultural practices (Zimmerer. 2010; Rueda and Lambin, 2013), lack of empirical evidence makes it difficult to conclude that sustainability certifications present significant environmental contributions (Blackman and Rivera, 2010). In addition, it is necessary to consider that environmental outcomes of these certifications are highly contextual, as depends on a great variety of factors that vary between geographies, production systems and type of program (Tejeda-Cruz et al., 2010; Dietz et al., 2018). Although these systems are currently focused in making elements associated to the economic and

social components more transparent (e.g. farm gate prices, production costs, quality attributes), one can argue that the same systems can be used to provide transparent records to facilitate monitoring and diffusion of environmental friendly agricultural practices, or to assess environmental footprint of coffee production. For example, these systems can allow to identify if a coffee is produced in areas designated for conservation, or provide a sequence of environmental indicators associated to the different processes and attributes in the path that coffee follows from the plot to the cup. Regardless these opportunities, it would be important to prevent these monitoring systems to become tools to impose control through surveillance, or ways of exercising digital colonialism over rural local communities.

In summary, the outcome of digitalization pathways to sustainability is not homogeneous. Factors beyond the socio-economic context in which these technologies are applied defines the resulting scenarios. Our evidence shows that technical characteristics themselves also contribute to draw specific trajectories. Because digital agriculture is composed of a mosaic of different technologies, several innovation pathways can coexist in the same agricultural system, as we have probed for the case of coffee.

### **3.7. Conclusions and recommendations**

Digital technologies are associated with high hopes for addressing sustainability challenges of the CVC. The way to do it, however, can be represented by different pathways. Our analysis of 20 tools, focused on digital advisory services, and digital marketplaces and traceability systems, identified two main scenarios on how digitalization is likely to affect different dimensions of sustainability. On the one hand, we found evidence that the knowledge and value systems associated with advisory services (specially tools for automatized analysis of information such as AI and computer models) reinforce a productivist perspective, which focuses on the diffusion of conventional-industrial agricultural practices to produce coffee for a commodity market. On the other hand, we found that a relational model, associated with digital marketplaces and traceability systems, facilitates communication between producers and buyers, allowing producers to access differentiated markets with added value. The participation of producers in these scenarios, however, is not symmetrical. Due to access barriers to technologies, more marginalized producers are more likely to receive generic information for conventional-industrial types of farming. In contrast, better-off producers, with higher access to more sophisticated technologies, have greater possibilities to benefit from tailored information and from participating in digital platforms oriented to differentiated markets. Cooperatives and NGOs', through their capacity to coordinate groups of smallholder producers, however, can to some extent, damp this dynamic.

Digitalization is often portrayed as a revolution for agricultural systems. In the case of the CVC, however, our analysis found that digitalization can be more about the optimization of conventional industrial production and extension models, and more efficient social coordination within already centralized power structures. There is a risk that digitalization is promoting a technological lock-in, perpetuating a production model with a high ecological footprint, while agroecological models and processes of adaptation to, and mitigation of climate change are overlooked. For the most part, digital tools for advisory services place producers in the role of passive recipients of information generated by a few central players (research institutes, individual agronomists), while in digital marketplaces and traceability systems, producers provide large volumes of origin information without reciprocal retribution. These platforms connect producers with other value chain actors, and better align farm gate prices with the physical product (concretization). However, the participation of producers in value capture remains minimal and dependent on the decisions made by other players. Digital technologies are transforming the power structures within the CVC, yet, this has more to do with a power recentralization in the hands of the new technological authorities, than with a true empowerment of producers.

Digital technologies present the potential to enhance the sustainability of agricultural value chains. However, to do so, the innovation process requires a broader scope of social and environmental considerations. Digital tools should be more inclusive with different production models, including more agroecological perspectives. A strong emphasis on producers' inclusion is necessary, providing them opportunities to participate in important decisions related to the way value, access, and knowledge is distributed through the different sets of technological systems that conform each pathway. The analysis shows that the digital gap is a powerful driver of exclusion processes, favoring the creation of hierarchies among producers. In order to provide equal opportunities for all types of producers, great efforts have to be advanced from multiple sectors to strengthen digital literacy and develop technological infrastructure in rural areas. Given the central role of Cooperatives and NGOs as supporting institutions (e.g. aggregating and representing groups of individual coffee growers), closer attention to the potential role of these organizations in democratizing access to digital technologies is recommended.

The described pathways are not the only possible scenario for the future of digitalization in the CVC. Through the lens of the three themes on which we have based our analysis, we identify some characteristics that digital tools for agriculture can integrate to engender alternative pathways: 1) open to different knowledge systems and alternative production models, 2) originated from a truly participatory process, 3) characterized by a decentralized control of information, 4) working under the principle of full transparency in the value chain and symmetrical information, 5) free or very low cost, 6) based on very simple technologies, 7) easy to adapt and re-script by the users. These characteristics can constitute a relevant input

to guide processes of development of digital tools for the agricultural sector that consider a sustainability approach (social, economic, and environmental). The emergence of alternative pathways towards sustainability in agriculture that includes the digital socio-technical system, can be supported through industrial standards and principles for the development of digital tools, that, in alignment with the previous points, were based in the principles of inclusion, transparency, and fairness. Additionally, legal frameworks can be put in place to provide incentives to develop processes of innovation aimed to design and implement open and fair technological systems. In any case, it is worth saying, that, although these considerations may contribute to developing more effective tools to support the transition towards a sustainable value chain, the resulting tools will not constitute silver bullets to solve the entangled socio-ecological problems that affects the CVC.

To conclude, in order to understand the trade-offs that digital technologies embody for society, the questions of 'what kind of socio-technical pathways are proposed by such technologies?', and what implications represent to all dimensions of sustainability, will always be relevant. To contribute to this discussion, we have proposed an analytical framework based on the technical characteristics of digital tools and their interaction with social systems. The evidence of this framework applied to the CVC shows that the pathways towards sustainability proposed by the process of digitalization are far from being straightforward. Because digital technologies are not all the same, neither do they present the same societal consequences, paying attention to their distinctive technical characteristics can help to create a more nuanced debate about the role of this socio-technical system for the sustainability of agriculture.

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## **4. How do coffee farmers engage with digital technologies? A capabilities perspective**

Hidalgo, F., Birkenberg, A., Daum, T., Bosch, C., & Quiñones-Ruiz, X. F. (2024). How do coffee farmers engage with digital technologies? A capabilities perspective. *Agriculture and Human Values*, 41(4), 1707–1723. <https://doi.org/10.1007/s10460-024-10574-3>

### **Abstract**

A reality-design gap in the conceptualization and practice of digital agriculture has been systematically reported in the literature. This condition is favored by the lack of understanding and inclusion of local worldviews around digital technologies. Informed by Amartya Sen’s capabilities approach, this study looks to bring stories of local appropriation to the spotlight. Based on a qualitative approach that included data collected through interviews with 73 households, the authors explored the way in which two selected communities of Colombian coffee growers are engaged in the use of digital technologies in material and symbolic ways. Three emergent themes - a relational way of farming, (dis)connected machines, and nurtured families and communities – articulate multiple interactions between farmers, farms, institutional programs, and technologies, that originate local forms of digitalization (and non-digitalization). This study points out the relevant role of situated ideas of development in positioning technologies in or out of the farm, and broader digitalization agendas in or out of farmers’ life projects. At the same time, it presents a critique of notions of universality that drive unquestioned quests for technification. In contrast, building on a relational perspective, this study calls for embracing a perspective of multiplicity within notions of development and innovation.

### **Keywords**

Digitalization, Capabilities approach, Coffee, Relational agriculture

### **4.1. Introduction**

A gap between the perspective of developers and proponents of digital technologies (electronic tools that generate, store, process, transmit, display and use data) and the reality of farming communities has been systematically reported in the social literature on digital agriculture and on Information and Communication Technologies for Development (ICT4D) (Prost et al. 2012; Heeks 2002; Dodson et al. 2013; Contreras-Medina et al. 2020; Rose et al. 2018; Eastwood et al. 2019). Some argue that a common practice in

digitalization in agriculture is to embrace a dominant development paradigm that fails to recognize the existence of multiple interpretations of the world, notions of development, and ideas of a desirable future (Beguin et al. 2012; Zheng 2009). Critical views argue that digital agriculture is dominated by a productivist and technocentric perspective of development (Bronson 2018; Bronson and Knezevic 2016; Kuch et al. 2020; Lajoie-O'Malley et al. 2020; Rotz et al. 2019a; Wolf and Wood 1997). This dominance not only contributes to originating practices of scientific inquiry, industrial production, and policy design, that continue the reality-design gaps (Rose et al. 2018; Macmillian 2018), it also prevents the recognition of users' preexisting knowledge (Coggins et al. 2022). In fact, on ground digitalization trajectories seldom match mainstream discourses and agendas that are becoming dominant in research, practice, and policy (Forney and Dwiartama 2023).

Even the research under the scope of responsible innovation (see Bronson 2019; Hellström 2003; Owen et al. 2013; Stilgoe et al. 2013), which advocates for a more inclusive approach in the design of digital technologies, tends to narrow down the possibilities to understand alternative perspectives of development, as it is often mainly concerned with identifying the mechanisms to promote the uptake of digital technologies, without much reflecting on what uptake really means for the communities, or whether it is actually their desired development pathway (Kleine et al. 2012; Zheng 2009). In the process of appropriation, the decision to reject a technology is as meaningful as the decision to use it. This conception challenges general assumptions associated with techno-centric perspectives of development. While from a techno-centric perspective, a lack of 'adoption' tends to be interpreted as a problem of access and digital literacy, in practice, the issue is much more complex.

To present an agency-centered perspective on digitalization, the aim of this study is to explore the current ways in which two selected coffee growers' communities nestled in the mountains of Colombia are engaged in the use of digital technologies in material and symbolic ways. Namely, the position that these technologies have in their imaginary. The study particularly aims to understand how these technologies are integrated into the farming practices and life strategies of these communities. It recognizes local perspectives of development as powerful drivers of technological appropriation. By doing this, we look to move local stories of digitalization from the fringe to the center in critical debates around digital agriculture.

The relevance of this lies in an existing gap in the way the analysis of rural digitalization has been approached. In contrast with "spotlight digitalization" (Forney and Dwiartama 2023), and the diffusion of technologies (particularly from a linear perspective), the forms in which local communities are already engaged in the use of these technologies in their own terms are continuously neglected (Rose et al. 2018; Rose et al. 2016; van Delden et al. 2011; Rose and Chilvers 2018). For this reason, the examination of unfolding local interactions with digital technologies outside the frame of particular developmental

interventions or deployments of specific digital tools remains a blind spot (Rose and Chilvers 2018; Rose et al. 2018). This paper looks to contribute to the literature by analyzing one of these highly contextual processes of digitalization and linking it with broader narratives of digitalization. We look to provide evidence on the way local processes of digitalization unfold in unique forms, potentially divergent from these broader narratives and digitalization agendas. This is conducted through the articulation of the different ideas of development that farmers and proponents of digital agriculture can hold, pointing out the negotiations and tensions that occur in the space of interaction.

Emerging social research that examines processes of cultural appropriation and perceptions towards digital technologies in agriculture has predominantly centered around the Global North (Klerkx and Rose 2010; Rose et al. 2018), and in industrial farming contexts (Bronson 2019). For this reason, there is a pressing need to overcome geographical and cultural bias in research about digital presences in rural spaces (Cieslik et al. 2018; Mann 2018; Sulaiman et al. 2012; Ash et al. 2018). Building on emerging contributions such as Dwiartama's work in Indonesia (Forney and Dwiartama 2023), and Abdulai's work in Sub-Saharan Africa (Abdulai 2022), we look to contribute to the body of literature centered in the Global South with a local analysis of digitalization in the smallholder family-type farms setting in Colombia.

For the analysis, we adopted a human-centered approach based on Sens' capabilities framework (1999). Under this framework, resources only become assets when they can be used by individuals to accomplish the life they value. This idea opens the possibility to explore multiple development perspectives. Through this conceptualization, we focused our analysis on the opportunity for people to use technologies to achieve their own particular goals, rather than on how technologies fulfill aspirations of dogmatic notions of development (those that compare development with economic growth or modernization). Thus, we were concerned to first understand what elements configure a valuable life for these communities, and next, how they use digital technologies to support the accomplishment of this life. Following a relational perspective (Higgins 2006; Darnhofer 2020; Forney and Dwiartama 2023), we conceive that farmer's agency in this process of appropriation is shaped by occurring interactions between knowledge, value systems, social institutions, and the agency of non-humans (land, plants, animals, technologies), in the search for integrating technologies into the life they find valuable.

The paper is structured as follows. The section below reviews the capabilities approach and its application in explorations of the appropriation of digital technologies. Subsequently the research methods adopted for this study are presented. The next section describes the findings of the study, which are organized around three themes that emerged from the data: a relational way of farming; (dis)connected machines; nurtured families and communities. These themes articulate the different social and material interactions that shape local engagement with digital technologies. Local values that underpin this process are also contrasted with

those expressed in dominant narratives of digital agriculture. Thereafter, the findings are discussed in relation to existing literature on rural local ontologies and the appropriation of digital technologies for agriculture. We conclude by summarizing the main findings, and suggesting relevant epistemological considerations to study the role of digital technologies in the lives of farmers, their families, and their communities, highlighting the evidence that shows that rurality is a world of many worlds.

## **4.2. Capabilities approach, agency, and farmers' interactions with technologies**

Sen (1999) defines development as the freedom that people have, to live the lives that they value. In contrast to more orthodox notions that make development a convention comparable to economic growth, this perspective focuses on the expansion of people's agency to pursue their own goals in life as the basis for human development (Kleine et al. 2012; Zheng et al. 2018; Jimenez and Zheng 2018; Poveda and Roberts 2018). Development goals, consequently, are not fixed but contextual and multifaceted. Financial resources and production can be inputs to build development as much as the protection of freedom, political participation, socio-cultural practices, norms and traditions, or the provision of public goods (Crocker and Robeyns 2012).

Central to Sen's conceptualization of development are the concepts of functionings and capabilities (Kleine et al. 2012). Functionings refers to the various things a person can value doing or being in life, while capabilities are the functionings that a person can actually achieve (Sen 1999). According to this approach, the ends of well-being and development should be assessed in terms of people's capabilities and choice, that is, their effective opportunities to be who they want to be, and the possibility to choose from these opportunities, the options they value most (Crocker and Robeyns 2012). In the process of articulating his capabilities approach, Sen (1985) described that the freedom to undertake the actions and engage in the activities that lead to a state of existence associated with well-being is what makes life valuable. Following the work of Sen, Carolan (2018) expressed that goods, services, and rights have no intrinsic value; it is the possibility of using these resources to produce valued outcomes that transforms them into assets.

Building on this perspective, technologies can be considered assets if they can be used to obtain meaningful goals in life, if chosen to do so, resulting in the expansion of human capabilities. The idea that technologies can be perceived as "enablers to the pre-existing capabilities of human beings" (Banerjee 2013 p. 79) aligns with this value of technologies as a tool for the expansion of human-development. A consequence of this idea is the transition from a technological to a human-centered perspective in technology studies (Madon 2004). Following the capabilities approach, in this work we place farmer's agency at the center, rather than

the technical possibilities of the technologies. This approach requires paying special attention to the motivations that drive a person's actions, and their adaptive preferences (Peter 2003). It also involves understanding technological appropriation as an active process of selecting, rejecting, and adapting, in the search of living a valuable life. Agency can be exercised individually and collectively, and does not always mean pursuing one's own self-regarding goals. It can also involve helping other's to achieve their goals or forming associations to pursue common goals (Crocker and Robeyns 2012). This idea of technological appropriation highlights the agency of farmers in constructing technologies, echoing Sen's proposition that individuals and groups themselves should shape their own destiny, and be active participants in change, rather than passive recipients of assistance (Sen 1999). This understanding links the capabilities approach with the idea that technologies are socially constructed (Bijker 1995; Hughes 1987; Orlikowski 1992).

Farmers are rarely passive participants in farm innovation (adopters), but rather transformation agents through resistance and negotiation with other human (e.g. peers, developers, promoters, practitioners) and non-human agents (e.g. plants, animals, machines, computer programs). Simultaneously, technologies contribute to reshaping the social context within the farms. Cash et al. (2006) argue that "new technologies are not adopted as if they were ready-to-wear fashion but rather sewn, in bits and pieces, into the fabric of the users' social setting and existing practices" (p. 474). Accordingly, the meaning of a technical artifact is not only the result of design, but is also given through the process of interaction with the technology (Pirnejad and Bal 2011). Thus, the meaning and performative role of technologies can not only change over time but can also be different for different actors (Sterne 2003).

Capabilities and personal agency, however, are not solely the result of the intrinsic capacities of the individual (Crocker 2008), but rather are entitlements made possible or constrained "by the social, political and economic opportunities available to us" (Sen 1999 p. xi-xii). The set of these opportunities is described by Alsop and Heinsohn (2005) as the 'opportunity structure', which is the constellation of "psychological, informational, organizational, material, social, financial and human assets" (p. 8) that a person has at hand to make meaningful choices. The opportunity structure is determined by both formal and informal institutions, such as laws, social norms and customs, which ultimately result in varying levels of empowerment (Kleine et al. 2012). Social structures, including policy-making, industry, markets, and scientific production, the assemblages of these structures, along with the institutions that they generate, play a crucial role in driving socio-technical pathways - both those that are allowed and those that are not (Klerkx and Rose 2020; Pigford et al. 2018), through the technical projects and the imaginary supporting those projects (Gidley 2017). On the other hand, technology itself is an important component of the opportunity structure. First, it influences people's behavior and has the capacity to shape political systems and social

relations that distribute power and authority (Winner 1980). Second, as previously described, technologies can be used as assets to achieve a valuable life.

The agency of farmers is not absolute, as it is constantly shaped by material relationships established with technological and biophysical entities and contexts. It is well known that farmers continuously have to 'negotiate' with and work around uncontrollable weather, unruly plants, diseases, breakable machines, and financial constraints (Darnhofer 2020). Complex biophysical settings, for example, have been recognized as challenging scenarios for processes of industrial transformation of agriculture (Goodman et al. 1987), a relationship that favored processes of agricultural homogenization for the sake of industrialization. On the other hand, agricultural landscapes are also a product of cultural forces. Therefore, biophysical arrangements are also shaped by farmers' values and goals, and their quest for a valuable life. The concept of 'tinkering' as it is used by Higgins et al. (2017), is useful to understand the operation of agency in technological appropriation on farms. They describe tinkering as a process of 'negotiation, work, and work around' technologies in response to technical and biophysical constraints. However, it is also about using the affordances of these technologies to care for their farms. We argue that this process is heavily influenced by cultural relations, given that tinkering is an interpretation and adaptation (physical and symbolic) of technologies by farmers, to align with local farming practices and identities.

Technical attributes of technologies have a significant impact in the possibilities they afford to farmers, how they are used, and the operational requirements. Therefore, these attributes also shape the agency of farmers. In the context of digitalization, asymmetrical access to connectivity, energy sources, equipment and devices, and information, which has strong rural dimensions (Pfeizer et al. 2020), favor processes of hierarchization and exclusion, commonly referred to as the 'digital gap'. This refers the gap between the technological haves and have nots (Rama and Wilkinson 2023). On the other hand, interactions with non-human agents also shape farmer's agency and their interactions with technologies (Higgins 2006). Relational approaches in rural sociology call for understanding farms as entities with agency and affectivity (Darnhofer 2020). These attributes influence the way farmers engage with technologies responding to the agency of the farm. Recognizing these properties in the farm and its different elements allows the understanding that agricultural technologies, when interacting with plants, animals, and the land (which they permanently do), are not simply 'governing' passive entities, but establishing relationships with agents with affective and decision capacity. Moreover, the process of digitalization is reframing notions of agency in rural studies. Algorithms, smart devices, and automated machines, act in material and regulative ways in the cyber, physical, and social spheres, affecting the agency of human and other non-human agents (Lioutas et al. 2019; Rijswijk et al. 2021).

To summarize, we argue that using the capabilities approach to explore social interactions with digital technologies presents the next conceptual implications in our analysis. First, through the concept of ‘functionings’, it is recognized the coexistence of multiple ideas of personal and collective development, and correspondingly, multiple development pathways. Second, this approach integrates the idea that technologies are socially constructed, acknowledging the active role of farmers in innovation through processes of selection, adaptation, appropriation, and rejection in their quest to live the life they value. Third, the concept of ‘opportunity structure’ allows to explore the ways in which social structures and the institutions they do or do not engender, and material relationships between humans and non-humans, enable, constrain, and mold farmers’ interaction with digital technologies. In other words, the notion of ‘opportunity structure’ implies that agency is co-constructed.

### **4.3. Methods**

#### **4.3.1. Context of the study**

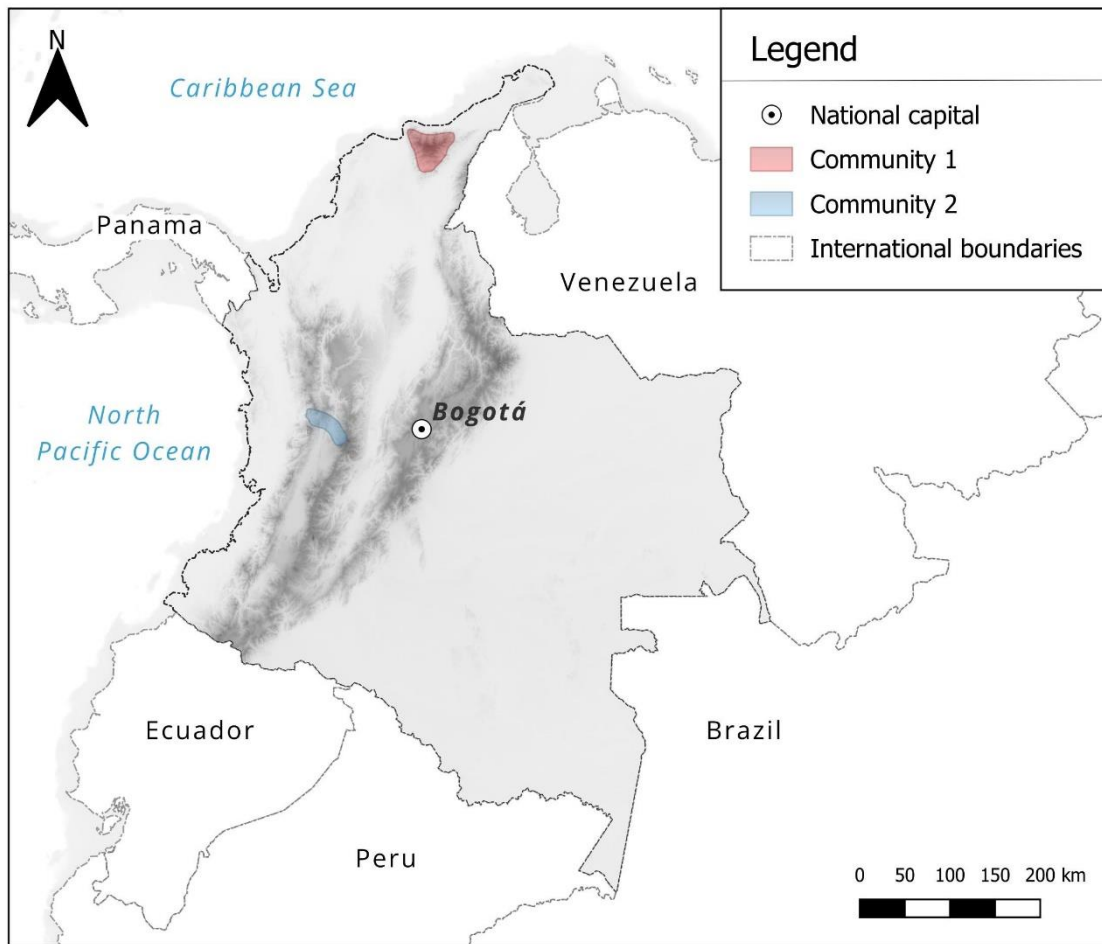
This study examines the relationship between digital technologies and two coffee-growing communities in Colombia, analyzing their current material and symbolic interactions. For this examination, we followed a human-centered approach, informed by Sen’s capabilities approach.

The first community is located in the northern part of Colombia, in the Sierra Nevada de Santa Marta mountain range, which is the highest coastal mountain range in the world. It is also one of the geographical indications (GI) for Colombian coffee (national system), and was awarded the Protected Designation of Origin (POD)<sup>14</sup> in 2017 (European system). The second community is located in the central-western region of the Colombian Andes, in one of the regions with the greatest tradition of coffee production in the country (Figure 3). Both communities share characteristics of the UNESCO World Heritage site named the 'Coffee Cultural Landscape' (Muñiz 2016), a designation that encompasses a combination of agroecological conditions, socio-economic processes and cultural identity, all built around coffee production. Some of the representative elements of this cultural landscape present in the communities of this study, as well as in other coffee-growing communities in Colombia, are characterized by the dominance of Arabica coffee plantations in a mountainous terrain. The production is dispersed and carried out predominantly by smallholder growers living in isolated areas with limited infrastructure. The two communities also have a

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<sup>14</sup> Geographical indications (GIs) are names given to products that present unique qualities associated with their area of origin. The Protected Designation of Origin (PDO) is a form of regulation that certifies that i) a product is originated in a defined area, ii) that its qualities are defined by the geographical environment with its inherent natural and human factors, and iii) that the production and processing take place in the defined geographical area (European Commission, 1992).

long farming tradition, a wealth of experiential knowledge, and a strong shared cultural identity. While there is high participation in farmer's cooperatives, the family acts as the central unit of social organization, around which, life strategies and decisions are coordinated. Table 9 presents some geographical and agricultural characteristics of the sample included in this study.



*Figure 3 Location of the areas of study*

Not only in the study areas but throughout the country, the institutional framework for technological transfer in the coffee sector is represented by the Federación Nacional de Cafeteros (FNC). This federated organization is the central authority involved in policy making, research, extension, and trade in the Colombian coffee sector. It has even been delegated by the national government to regulate the industry. Historically the FNC has played a key role in processes of innovation. For example, it has set technical guidelines for agricultural practices (De La Hoz Montes et al. 2019; Guerrero et al. 2017), implemented the

national genetic program to develop new coffee varieties (Alvarado-Alvarado et al. 2005), promoted technological packages related to industrialized production (monocultures with synthetic inputs) (Camargo and Espitia 2016), mechanization and technification of production and processing and more recently encouraged a shift towards production oriented to specialized markets linked to quality and sustainability standards (Dietz et al. 2019). On occasions, pushing these transformations by exerting its influential position over farmers (Sanabria-Gómez and Caro-Moreno 2020). The FNC has also ventured into the field of digitalization, with initiatives such as a smart card for the identification of coffee growers and for monetary transfers (Marín-Torres 2008) and delivering tablets to access digital content related to coffee production (Zapata and Marín 2015). According to Zapata and Marín (2015), in 2010, 700 of these tablets were delivered in the same region where community 2 is located; however, during this study there was no evidence of their use or that this program was known by the farmers.

*Table 9 Geographical and agricultural characteristics of the sample included in this study*

<b>Community</b>	<b>Region</b>	<b>Municipalities</b>	<b>Production model</b>	<b>Average farm area (Ha)</b>	<b>Hired labor</b>	<b>Altitude above sea level</b>
Sierra Nevada de Santa Marta	Caribbean	Santa Marta	Organic	5	Yes	1300 - 1900
		Aracataca				
Cetral-Western Andes	Andean	Santa Rosa de Cabal Concordia Betulia	Conventional	16		

#### **4.3.2. Data collection and analysis**

The data collection took place between December 2021 and January 2022. Two of the authors had previous access to the coffee grower communities. One of the authors already had research experience with one of the communities (See Quiñones-Ruiz 2021). The research plan was presented to representatives of both communities who expressed their interest and consent to participate in the research.

Data were collected through semi-structured interviews. The interviews were conducted at the household level, meaning that, in addition to farmers themselves (F), other family members, such as the farmers’ partners (P), and the children (C), voluntarily participated in the interviews. We made this decision paying attention to the central role of family in the coffee farms and following the idea that decision making on the farm is a process of deliberation between various family members (Darnhofer 2020). In total 73 household

interviews were conducted (Table 10). All participants were informed of privacy and ethics practices, and their informed consent to participate in the research was secured.

*Table 10 Number of interviews conducted in each selected community*

<b>Community</b>	<b>Role</b>	<b>Number</b>	<b>Average age</b>	<b>Average experience with coffee (years)</b>
Sierra Nevada de Santa Marta	Farmer (F)	22	52	30
	Partner (P)	-	-	
Cetral-Western Andes	Children (C)	3	22	35
	Farmer (F)	36	50	
	Partner (P)	8	57	
	Children (C)	4	19	

Access to the interviewees was obtained through three different strategies. The first strategy consisted of conducting interviews directly on the farms. The second strategy involved conducting interviews in meetings organized by the coffee producers' organizations. A total of three such meetings were attended in the Sierra Nevada de Santa Marta area. No meetings took place while the researchers were in the community of the Andes. The third strategy involved interviewing farmers on the spot when they went to sell their dry parchment coffee to the buying points. A total of five of these sessions were carried out (three in the community of the Andes, two in the community of the Sierra Nevada de Santa Marta). The interviews lasted between 35 and 90 minutes each time and covered the current use and perceptions of everyday digital technologies such as mobile phones, smartphones, computers, tablets, and other technologies closely associated with digital agriculture such as drones and robots. The questions focused on the role of these technologies in everyday practices, the main goals, aspirations and challenges of the household, and how the role of these technologies is understood in relation to these aspects- They also covered general attitudes towards these technologies, including elements of trust in the devices and the information, and perceived benefits and risks derived from their use.

Interviews were digitally voice recorded and subsequently transcribed in the original language (Spanish). Manifest and latent content analysis of the interview transcripts were conducted using inductive coding (Charmaz 2006) to identify emerging themes. These themes helped to uncover patterns of use, underlying perceptions, and the association of technologies with the life interviewees value. The themes emerged from the reported uses and perceptions addressed in the interviews.

## **4.4. Results**

From the interviews three different themes emerged that articulate the uses and perceptions of digital technologies by these communities of coffee farmers. These themes will be identified here as *a relational way of farming*, *(dis)connected machines*, and *nurtured families and communities*.

### **4.4.1. A relational way of farming**

Respondents' descriptions of work and life on the farms largely speak about the practice of a relational way of farming. Labor is described as a process of reciprocal, non-hierarchical, relationships with the different elements of the farm, such as soil, water, plants, and animals. The relational way of farming, as described by the interviewees, also highlight the importance of social relationships with family, workers, and peers, which is further explored in the third theme. According to the respondents, the reciprocal relationship with the farm is what allows them to learn from direct experience with the land and achieve their goals through processes of dialogue and 'negotiation'. This is reflected in the way they describe their experience of farming.

The land has taught me a lot, when you are in the plot, walking through the trees, talking to the trees, looking at the tree, you begin to merge with it, and then we become friends (F5).

This farm is an example of sustainability, she<sup>15</sup> remains beautiful in good times in bad times, you have to keep her in good shape because she must respond with production (F6).

It is described that direct experience with the land is essential for being a 'good' farmer and an important component to build a sense of identity and pride. Some interviewees expressed that digital technologies do not occupy a relevant place in farming practice; on the contrary, they are generally perceived as sources of interference with the direct relationships that underpin and signify the experience of being a farmer. Technologies with which they are familiar, such as cellphones, smartphones, computers, and tablets, are perceived to belong to a different sphere than farming practice, incompatible and non-applicable in the fieldwork. Consequently, they are not perceived as relevant components of their opportunity structure for farming. The interaction with these technologies is downgraded, while "hands-on" work occupies a central position. Experiential knowledge and the associated ability to interpret the components of the farm themselves and make decisions autonomously are essential functionings, being relevant sources of self-confidence and pride.

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<sup>15</sup> Farm in Spanish language, the mother tongue of the interviewees, is female.

Here (showing a cell phone) I look for calls and make calls. It's just that I haven't started to explore it either. It is that I am very ignorant, although, for example, what do you (referring to the interviewer) know about cultivation? One was born in this (the plantation), one knows from sowing the seed to make it to produce (F21).

My job is not on the computer, my job is simply field manager, and the field is not managed with a computer (F27).

Technical attributes of smartphones, computers, and tablets, also play a role in the way the interviewees position these technologies on the farm. In general, they are perceived as fragile devices, not compatible with harsh and uncontrollable fieldwork conditions. Farmer 17 describes this perception in the following way:

A smartphone is very good, but is very fragile, and you are very dedicated to the work, smeared with so many things. What is one going to do with it? So, one doesn't use it, one working cannot use that (F17)

An antagonistic relationship is not only described in terms of the device's inability to withstand common farming conditions, such as water, dirt and falls<sup>16</sup>. It is also associated with the idea that, farmers themselves, precisely because of being exposed to those harsh working conditions during their life, do not fit with the operation of these 'fragile' devices. In other words, farmers are 'made' for work in the field; digital technologies are not.

What happens is that I am very manual at work. I keep my hands very stiff due to rustic and manual work, so the digitization is not so fast for me, I am trained for something else, I have very heavy hands (F6).

Contact with the land is also a fundamental component of rural identity, providing a sense of enjoyment in working and living on the farm. "Feel good," "like," and "enjoy" are expressions that appeared recurrently when interviewees narrate their work and life on the farm, expressing a correspondence with their functionings. This does not mean that rural work and life is considered free of difficulties, but it reflects the existence of fundamental values and benefits (more often intangible) in this life. As expressed by Partner 2: "Despite the difficulties we like it, we like the farm, we like the coffee. From the farm, one gets what one needs."

Interviewees continuously contrast values of rural life, such as freedom, tranquility, abundance, and more natural and healthier environment, with contrasting conditions of living in the cities, such as traffic, stress,

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<sup>16</sup> Mobile phones are considered more resistant and therefore more compatible with field work, at difference with smartphones, it is more common to bring these devices to the plots.

insecurity, high living costs, or noise. This distinction helps to signify the value of living and working on the farm, linking this lifestyle with positive feelings. These conceptions have different consequences on the way these communities perceive and use digital technologies. Occasionally, these technologies were associated with urban life and the loss of contact with nature. In the words of Partner 6: "In my time, we did not have internet, and well, I think that everything was better. We had the childhood of being up in trees picking mangoes." For some other respondents, digital technologies can actually fit into the experience of living and having contact with the farm. These situations are prone to trigger engagement with technologies such as smartphones and tablets since the interviewees acknowledge an alignment between these technologies and elements of a valuable life. Farmer 7 described his experience with these technologies as follows: "I like having a good smartphone because of the pictures. I take videos and pictures; they are very beautiful." When asked about the videos and pictures he takes, he proceeded to explain "everything, different pictures and videos, I can take a picture of a tree, a coffee plant, a machine, a person, myself, in the house, everything." In this case, a smartphone, serves as a tool for documenting evoking both living and inanimate elements of the farm, as well as facilitating a meaningful connection with these elements. Thanks to this affordance, it becomes an integral part of their opportunity structure.

The capabilities approach contributed to identifying a set of values associated with working and living on farms. These are underpinned by a relational ontology. In turn, these values contribute to locating digital technologies both on and off the farm.

#### **4.4.2. (Dis)connected machines**

Interviewees were asked to describe their perceptions of emerging technologies such as drones and robots and were invited to reflect on the role of these technologies in agriculture. The intention was not to compare them to technologies like mobile phones, smartphones, tablets or computers, as they belong to different categories. Although the respondents had not physically interacted with these technologies, they all indicated having an idea about them, and symbolically positioned them in the farm, farming practice, and community. During the interviews, it became evident that two key elements influenced the interviewees' conceptions of these technologies. First, elements of science fiction, especially the representations in cinema -where robots are predominantly portrayed as a threat to humanity-. Second, a pilot project for the mechanization of coffee harvest in Colombia, carried out by the FNC as part of their broader innovation program. These elements intertwined with the ontology of the relational way of farming, have resulted in particular perceptions and attitudes towards these technologies.

From “wonderful” to “scary,” the interviewees expressed different ideas about robots and their role in the practice of agriculture. Regarding the mentioned pilot implemented by the FNC, the proposed technology consisted of a handheld brushcutter-like machine that made the coffee fruits fall to the ground by means of vibration applied to the branches of the trees. Due to a lack of distinction between green and ripe fruits, and the steep slopes of the plots that caused the fruits to roll downhill, this technology did not produce the expected results. However, the project was widely disseminated, appearing in national news (Noticias Caracol, 2018), and on the FNC's social networks (FNC, 2020). The process constitutes a clear case of a reality-design gap, linking institutional, technical, and biophysical elements, and resulting in lasting consequences on the attitudes of these communities towards mechanization and automation. Most interviewees referred to this pilot and its lack of effectiveness when describing their own ideas about the opportunities of emerging technologies in coffee production. In this way, a process of innovation emerged from the institutionality contributed strongly to develop generalized distrust towards the ability of robots to work on the farms. On the other hand, some respondents expressed seeing robots as a promising opportunity. The following quotes illustrate these contrasting conceptions:

I kind of still don't believe in that, because the robot, well, it would be an important thing like in an office. They (the FNC) brought a harvesting machine here and that didn't work, that machine didn't work (F53).

How nice it would be to place a fungicide can on a robot, and with that spray the coffee. If that existed to spray the coffee from the air, that would greatly help to avoid carrying the sprayer and having contact with the fungicide (F13).

From the interviews two orders of incompatibility between robots and coffee production surfaced. Contributing to raise the skepticism in these technologies. The first order is located within a symbolic-technical relation, expressed in a perceived mismatch between the skills needed to be a good coffee grower (harvester to be more precise) and the agentic (in)capacity of the robots. The second order can be described as a perceived incompatibility between machines and nature.

For most interviewees, producing coffee requires a particular 'know-how.' That is, particular skills, meticulousness, and sensitivity, even “passion” or “love” as some respondents expressed. It also requires the ability to adapt to different contexts and to act effectively in conditions of high complexity and variability. For the interviewees, these abilities cannot be developed by robots because they are associated with experiential knowledge obtained through several years of work, and some capacities inherent to the human condition such as empathy, instincts and sensitivity. It was described how the value of coffee is given by the dedicated work of human beings, and attributes of the quality of coffee were associated with a handcraft process. It is perceived that the introduction of machines would affect the quality and in general

would be against the philosophy behind producing a 'good' coffee; a component of the relational way of farming and driver of their functionings around working and living on the farm.

Coffee is so artisanal and it should be so artisanal. Obviously, you must create conditions for the work not to be so difficult, but I think that so much technology could really affect the coffee process, because if you know about coffee, you know that in such dedicated selection, in such dedicated washing, there is a good cup of coffee. So, it would really be a bit mechanized, doing it with robotics or so much technological tools, could lose that quality (C7).

An established interaction between the biophysical characteristics of the farm and the technical attributes of robots also contributed to attitudes of mistrust in the capacity of these machines. Interviewees stated it clearly: robots are not suitable for working on the mountainous terrain that characterizes the coffee plots.

It is a risk (that a harvesting robot) loses control in the coffee plot and damages it, or that it rolls over and falls on a person (F22).

The farm as a whole, along with its various biotic and abiotic elements, are endowed with sentient capacity by practitioners of relational farming. Fundamental elements of this conception, such as empathizing and caring, contribute, in turn, to defining certain positions towards robots and their place in the farm. For several respondents, the presence of robots can be detrimental to the farming experience by disturbing the natural environment where the practice of farming takes place. Some interviewees pointed out that robots and machines in general are not only incompatible with nature but can also do harm or reduce its well-being.

Mechanize the coffee system? No. Coffee is a domestic animal that requires love, and this can be in person only. I don't see it, because the plant is stressed and if the plant is mistreated, production and quality will drop. For example, machines produce noise, I believe that vegetable matter is incompatible with noise, the wild system is better. To add a strange element to live with them, such as mechanization, I don't think it's favorable. Let's look at the plants on the farm, I can show you an example, you cannot compare this banana plant with any other in the farm, and this is not because it has a special treatment, the same, but it has better foliage, better bunches. It was planted next to my office, what can we observe? The plants that are participating in community life realize what it means to live in a community, and give a better response. So look, we're not telling lies, we're talking about facts. So one says, well, could it be that if we mechanize, we add noise, we mistreat the plants mechanizing them, will we have better quality or better well-being? No (F34).

A relational way of farming creates connections with the land. However, more commonly, there are perceived disconnections with digital technologies. In these interactions, the technical attributes of mobile phones, smartphones, tablets, computers, drones, and robots, and their relationship with biophysical contexts and their agentic capacity shape these positions. This does not mean that these technologies cannot find a place within these agricultural communities. From a capabilities lens, when these technologies are paired with the elements that these communities consider valuable in life, perceptions and appropriation take a different form. This is represented in the third theme.

#### **4.4.3. Nurtured families and communities**

Exploring the elements that farmers find valuable in life revealed the centrality of family. The main goals are to ensure that the family remains together, promote collaboration between its members, progress and thrive, and take care of the home, including maintaining and improving the physical spaces where they live.

The small farm is the most solid, 2 to 3 hectares are solid because you involve your work, your time, part of the family labor, and you can generate a good standard of living because everyone works for the family group (F6).

Technologies such as mobile phones and smartphones have become important tools for communication and for maintaining connections between family members. These technologies are deeply integrated into people's routines and life strategies. Consequently, significant economic resources are allocated to access these devices and grant connectivity, despite the economic burden that this represents. Time is also invested in carrying out autonomous learning processes. If digital technologies do not have a material and symbolic place in the plots, they do occupy a relevant place on farms, within homes and in family life.

Well, to me, they are very good (digital technologies), it also depends on knowing how to use them, but it is very good, because if one realizes it, you are not with your family, but the way you communicate, it is as if you were with them (P4).

When I need something, I call. I found it difficult, complicated, as I tell you, one is not used to these kinds of devices, but the saying goes that nothing is difficult. The children, one has the children to help them, what one wants is to have these technologies to have communication with them (F48).

A fundamental element behind the ideas of progress and thriving is facilitating children's access to education. Paradoxically, although the respondents recognize the values of rural life and the practice of agriculture, they simultaneously act in a permanent search to provide their children with education that will

help them migrate and find work in the cities. Associated with this quest is the perception of an uncertain future of agriculture, the experience of burdensome working conditions, and high levels of economic vulnerability. Furthermore, the increased access to education in recent times, and the influence of Western ideals of modernity -which equate progress with professionalization, job acquisition, and leaving the countryside to live in the city- have also shaped the desire of different sets of functionings for their children.

She (the daughter) loves the countryside, but she also wants to improve herself, she thinks a lot about her daughter, she should look for the city, for the study that she deserves, where she can have training, and truly, if I find the way to set up a business for her in the city, I will try to set it up (F37).

Prevalent connectivity limitations and economic constraints strongly hinder the use of digital technologies on farms, affecting the opportunity structure of these communities and reflecting an important digital gap. However, households also showed strategies to access and use these technologies when the goal is the education of their children. This is evidence that when technologies align with people's valuable things in life (e.g. education for the children), these technologies acquire a special meaning. This situation promotes processes of technological appropriation. The following quote, shared by Farmer 42, exemplifies this relationship: "I want my daughters to progress, allow them to study, so that they can defend themselves. That's the best inheritance. Each one has a computer; I bought it for them." They also work around these constraints when using mobile phones and smartphones for communication: "Here the signal is very bad, my children have to walk up there to look for a signal (H2)."

The opportunities to work around the constraints are not available for everyone, which restricts the use of smartphones and computers on farms. There is a continuous struggle to overcome problems of connectivity and the cost of technologies; however, this cannot always be achieved. Moreover, interviewees showed a lack of motivation to work around these constraints if the use of these technologies is not prioritized in their life strategies.

We spent two, three days without a cellphone signal... internet, well no. If one is going to acquire it, it is at a very high cost (P1).

We need an antenna and on the other hand we have to think about something satellite, but it always generates costs, so sometimes other priority things that we have to choose one, but connectivity is always difficult here, for that reason one doesn't have a laptop (F49).

In the context of nurturing the family sphere, the interaction with digital technologies is not always perceived as a positive element. Some respondents expressed concerns about the excessive amount of time that people spend on the internet (especially, but not exclusively, younger generations), addictive conduct,

and the way this process can erode family relationships. These elements of excessive use and addictive behavior that are commonly associated with urban life, also shape interactions with these technologies in rural households.<sup>17</sup>

Family things are coming to an end, because here, people who live in the town visit me and they are glued to the internet all the time, and we are at lunch and the young people do not pay attention. Even people, they are with the cell phone all the time. I think we are becoming very addicted to cell phones. I include myself. I have a lot of work, I feed workers and I use a wood stove, everything is more complicated, but the little time I have left, I am with the cell phone in my hand (P6).

Beyond the family sphere, households are immersed in the community, and maintaining this connection is another fundamental goal for the interviewees. Being part of the community and participating in the maintenance of the social fabric contributes to well-being and are important components of the life strategies to adapt and prosper in the rural ambit where the conditions of isolation, vulnerability, and the construction of social identity, define strong relationships of interdependence. This dynamic influences the way these communities use and perceive digital technologies. On the one hand, communication technologies are considered relevant tools for social cohesion and cooperation at the community level (collective functionings). On the other hand, robots as part of the process of agricultural mechanization and automation, are perceived as a peril for labor relations and the regional economy. The following quotes portray these interactions:

I'm in a group of coffee growers on WhatsApp, associates are there, a large group. Any information, that a thief stole a chainsaw and that he is in such place, and there everyone seeks him, and locate him in less than nothing, that is a great advantage, or a meeting that is going to take place in such a day, then it's important. That group was created by us coffee growers (F37).

Well no, robots no. For me it shouldn't be, since coffee support too many families, and if there were that, totally, there would be more poor people, then for me it would not be a good idea, we would not use it on the farm (F38).

Interviewees perceive that robots have the potential for producing economic and social benefits. On occasions, robots were associated with higher productivity, reduced labor costs, and the simplification of

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<sup>17</sup>Despite a clear separation between the rural and urban worlds, there is a continuous flow of materials, information, labor and capital between them. This exchange contributes to shaping cultural processes of transformation with elements of syncretism and the re-scripting of social values and conducts. According to Gibson et al. (2013), households are “permeable” to different sorts of influences through these different flows that occur through “porous boundaries.”

farm management. However, generally, these benefits do not outweigh the social risks associated with the loss of rural jobs. For this reason, robots tend to elicit more serious concerns than optimism.

I would not like to have machines here replacing the workers because there are many people who depend on the work, robots can harvest more, but that robot does not receive a salary, so the people who live from this, what do we do with them, or what reaction will they take? For me it's not viable (F27).

If a robot comes here, there will be no work for the harvesters. It does not look good to me, I would not use it, even if the benefit for me was greater. For what I am going to pay 20 workers, perhaps one of those robots can make it, it would be better, but there are also people who are left without livelihood, is not good (F40).

Some positive opinions, related to economic rationality, were also expressed, although to a much lesser extent. The next opinion from Farmer 1 exemplifies this: "Look, spraying with drones is coming. I wish I could afford to rent that or have one of those... I like it, because since one can save labor, costs drop." This heterogeneity within the communities adds another layer and scale to the notion of multiple coexisting views and the associated forms of socio-technical interaction. We found evidence of the diversity of elements that can be considered valuable by farmers and their families, and how different functionings coexist, opening opportunities for different forms of appropriation and opportunity structure configurations. What is apparent is that technologies such as robots and drones have not achieved a level of diffusion to spark discussions between supporters and detractors in the selected group of interviewees.

## **4.5. Discussion**

The themes of *relational way of farming*, *(dis)connected machines*, and *nurtured families and communities* articulate the multiple situated social, technical, and biophysical relationships that shape material and symbolic interactions between the communities in the study and digital technologies. These interactions are highly contextual and rise local appropriation pathways that differ from dominant imaginaries and discourses surrounding digital agriculture and its different representations (Agriculture 4.0, smart agriculture, precision agriculture). Overlooking these local interactions and their outcomes is an important source of reality-design gaps in digitalization.

Broad imaginaries of digital agriculture are often framed outside of situated cultural and material contexts. In some cases, it emerges from non-existent rural worlds or non-rural worlds, and not necessarily informed by experience. This creates a fundamental difference from farming, and poses a challenge for integrating into development pathways of local communities, the socio-technical projects steered by these imaginaries. Farming, as described in the literature (Carolan 2016; Gosnell et al. 2019; Higgins et al. 2017; Layman and

Civita 2022; Darnhofer 2020) and evidenced in this study, is a relational process. To exercise their agency, farmers continuously navigate throughout institutional, technical and biophysical contexts, entities, and the network of interactions between these elements. Everything in the quest for living the life they consider valuable. In this navigation, which can also be described as the negotiation between coalitions of different agencies (McFarlane 2011), technologies have different positions in farmers' opportunity structure, depending on the possibility and choice of using -or not using- them to achieve their functionings. Contrasting with the apparent stability that characterizes mainstream socio-technical projects (Forney and Dwiartama 2023), local interactions with technologies result from what Latour (2005) described as localized and short-lived associations of human and non-human actors. This nature of associations is established between farmers, farms, and machines, to build the form of digitalization evidenced in this study. It is the "everyday digitalization," which differs greatly from the big narratives or "spotlight digitalization" (Forney and Dwiartama 2023). We contend the co-occurrence of an 'everyday non-digitalization' resulting from the tension between these contrasting visions.

The functionings described by the communities in this study account for components that, at times complement, and in some cases challenge, rational-capitalist logics commonly associated with mainstream digitalization imaginaries and projects (Bronson 2019; Hütten 2019; Rotz et al. 2019b; Birch et al. 2020). For the communities in this study, capital and production are valued components of their functionings (it is not necessary to romanticize them). However, non-economic values such as autonomy, care for the land, and cohesive families and communities, largely contribute to a valuable life. Individualism and competency (common elements in capitalism), share the space with collective goals and a sense of interdependence (a nurtured family, a nurtured community). These values of individualism and competition are generally associated by those interviewed, with urban life. Highlighting that mainstream digital agriculture, when neglecting non-economic and intangible goals, could be designed to better represent urban-corporate imaginaries, or rational-capitalist forms of agriculture.

While visions of agriculture, strongly influenced by techno-centric and productivist perspectives, describe farms as places where people do not need and do not want to be (Baur and Iles 2023), the communities of coffee growers in this study conceive farms as places where they need and they want to be (what they wish for their children can differ). Moreover, responding to the ideas of 'good' farming - that include experience, instincts, and empathy - farms were recurrently imagined as places where technologies such as robots and harvesting machines cannot and should not be. Therefore, while influential agri-tech corporations tend to imagine peopleless landscapes populated by smart machines and artifacts that liberate farmers from the 'burden' of agricultural labor (Bronson 2018; Baur and Iles 2023), the respondents in this study are precisely afraid of this scenario. Similar perceptions have already been described in rural sociology. It has been

reported that farmers are skeptical about robots having the capacity to interpret the elements of the farm as a good farmer can, to provide contextualized information, or the necessary ethics and “touch” to treat plants and animals properly (Kaler and Ruston 2019; Rose et al. 2018). Layman and Civita (2022), for example, reported feelings of guilt and empathy experienced by relational farmers, associated with the damage and pain caused to the land by using machinery.

The interviews depicted a relational way of farming not only associated with the relationship established between farmers and the land, but also associated with the value of social relationships that form the agricultural landscape. As has been expressed by Layman and Civita (2022), core to relational farming is the establishment of reciprocal relations with peers and the broader community. For Trivette (2017), relational farming has a lot to do with trust and caring for others. A comprehensive view of relational farming, derived from the application of a capabilities perspective, integrates the relationships between humans and non-humans and the network of social relations. This integrated perspective provided an informed understanding of the local forms of interaction with digital technologies. The connection with the farm (a point where digital technologies are generally identified as disruptors), is complemented by the connection with other human beings (family and community). Here, digital technologies, as social communication tools, are identified as enablers, and important components in farmers’ functionings and opportunity structure. This relationship contributed to locating digital technologies on or off coffee farms. It also points to the exercise of agency for collective goals, as has been recognized in conceptualizations of development from a capabilities perspective (Crocker and Robeyns 2012).

Structural determinants of technology appropriation, such as technological infrastructure, technical knowledge and support, biophysical contexts, innovation processes engendered by the institutionality, and the interaction between these different elements, configure the opportunity structure for using digital technologies at a local scale. Strongly driven by their functionings, and the important motivation they originate, the communities in this study employ different strategies to navigate throughout the multiple determinants of appropriation and work around the constraints. The centrality of social relations and the education of the children, for example, determine the willingness of farmers to work around connectivity problems, lack of digital skills, and costs of technologies. Cellphones are taken to the plots in case they are needed to make or receive a call, but smartphones are kept at home to protect them from damage. Farmers and family members walk, sometimes long distances, to find a signal for making or receiving calls, and these communities actively create WhatsApp groups to share information and coordinate collective action. However, not all farmers can work around the constraints, which are strongly linked to material and economic factors. More impoverished farmers find it more difficult to access connectivity and devices because of the costs, evidencing a prevalent digital gap with a strong economic dimension. This condition

echoes propositions of digitalization as a space for broadening social inequities (Abdulai 2022; Fraser 2019; Pfeizer et al. 2020; Seyedsayamdost and Vanderwal 2020).

A particular socio-technical interaction is illustrated by the use of WhatsApp. A process of appropriation originates from the connection with relevant values in users' lives, and from the opportunity to adapt the technologies to local practices and social expectations in terms of functionality, participation, and content. The case of the harvesting machine tells a different story, providing a perspective on how farmers also work around institutional programs. Better aligned with techno-centric perspectives and bypassing local cultural and biophysical contexts, the technology proposed by the FNC was ineffective and therefore rejected by farmers. The institutional project of technification tried to place a particular technology on the farm, but farmers placed it outside of the farm and their opportunity structure. This reality-design gap case, in turn, contributed to building attitudes of distrust towards robots, a different technology but with similar functionality. This represents the critical view that farmers have regarding the applicability of technologies in their functionings, namely their contexts and plans. This is a process described as the reflexive capacity of individuals and collectives to critically assess their engagement with technologies and their proponents (Forney and Dwiartama 2023). Thanks to their situated knowledge, farmers found it easy to identify how the spatial complexity of the plots, and the requirements for an appropriate harvest, strongly hinder the applicability of these technologies, rendering them useless and excluded from their opportunity structure. Paradoxically, the central institution of the coffee sector in Colombia was unaware of this relation and misinterpreted the biophysical and social context.

In the context of this study, the binarity conventional/organic is not translated into rational/relational farming. Expressions describing a relational approach to farming (biophysical and social) were found in both communities. Consequently, these communities expressed similar concerns regarding the impact of mechanization and automation on the biophysical entities of farms, the social fabric, and 'good' farming. However, it was found that multiple perspectives regarding technologies coexist also within the same community. For some respondents, there is no relationship between technologies such as mobile phones, smartphones, or tablets, and non-human elements of the farm. For others, these technologies can be used as tools to document and evoke the relationships that farmers establish with these elements. These technologies are commonly considered important tools to nurture the family and the community, however, they also can promote addictive behaviors that undermine social cohesion. These descriptions speak about a complex engagement with digital technologies. Contrasting with a linear diffusion paradigm, the process unfolds in twisted and complex trajectories. Owen et al. (2013) described innovation as a dynamic, undulating path, sometimes with dead ends. Meanwhile, messy entanglements of day-to-day human and non-human interactions engender particular forms of digitalization (Forney and Dwiartama 2023). In conversation with

these two ideas, we argue that from this messy entanglement, emerge equally messy material and symbolic engagements, with opportunity for fragmentation, contradiction, and ambiguity.

Disparate perspectives towards drones and robots were evident in the Andes community. For some, these machines are conceived as 'clumsy' workers and a threat to the social fabric of the community, while for others they are seen as potentially valuable aids in managing the farm. Following the perspective of multiplicity framed by proponents of farming as a relational process (Darnhofer 2020; Layman and Civita 2022), we argue that multiple forms of interaction with digital technologies can coexist in the study areas, and that the outcome of the negotiations between different perspectives remains open. As evidenced with other technologies such as coffee varieties, pesticides, or renovation cycles, it is likely that the ordering of digital technologies will vary across coffee farms.

## **4.6. Conclusion**

This paper makes two contributions to the critical literature on digital agriculture. Firstly, it applies a capabilities approach to highlight the relevant role of situated ideas of development in positioning technologies on or off the farms, as well as broader digitalization agendas, on or off farmer's life projects. Amartya Sen's capabilities approach presents a critique of the unquestioning pursuit of diffusing technologies across contexts based on a false sense of universality. Secondly, this study contributes to the emerging field of relational studies on local processes of digitalization in the Global South, by presenting a case of two communities of coffee growers in Colombia.

Through the integration of the concepts of functionings and opportunity structure, we were able to assemble the multiple negotiations between farmers' personal and collective goals, knowledge, institutional programs, and the agency of non-humans, that shape processes of digitalization. This study highlights that technological appropriation is a process of agency co-construction in the quest to integrate technologies with the life that people find valuable. The local outcome of this process, articulated through the themes of *a relational way of farming*, *(dis)connected machines*, and *nurtured families and communities*, is an emerging form of digitalization and non-digitalization. To explain this: in this study, digital technologies such as mobile phones, smartphones, tablets, computers, robots or drones, were described by respondents as incompatible (in material and symbolic ways) with the practice of farming; therefore, there does not seem to be much space for them in the coffee plots. The farm, on the other hand, as a space also composed of social relationships (a central component of a valuable life for these communities), provides room for digital technologies that work as communication tools (mobile phones, smartphones, digital social networks).

Centering the analysis around the underlying values in which farming practices and identity are rooted allowed us to identify important tensions between local practices and the broad digitalization agenda. The relational local ontology strongly contrasts with the techno-centric and productivist perspectives that seem to occupy most of the narratives and practices around digital agriculture, engendering opposing visions of a desirable future. By following mainstream and top-down techno-centric perspectives and overlooking the local cultural and biophysical context, the main institution in the coffee sector in Colombia (FNC) failed to implement a mechanization project for harvesting coffee, contributing to rising local attitudes of distrust towards emerging technologies such as drones and robots. At the same time, it revealed the critical view of farmers regarding digitalization, automation, mechanization, and ideas of the 'good' farmer and the 'good' farming.

We consider that integrating in this study the perspectives of different family members (partners and children) provided a valuable understanding of the local interactions with digital technologies. The study shows that decisions at the farm level and perceptions regarding these technologies are shaped through dialogue between views, practices, and goals of different family members. We encourage social researchers to engage more often in household approaches when exploring local forms of appropriation. Considering the integration of smartphones and cellphones and WhatsApp in the routines of these communities of coffee growers, as well as the key role in facilitating collective communication and action, we consider that exploring dynamics such as imitation, the pressure to be excluded from these networks, and the need to conform to social practices, can provide valuable insights into understanding the not-so free choices in technological appropriation.

In the process of framing the mainstream picture of digitalization, it is possible that local stories of appropriation go unnoticed. If these stories are not better positioned in critical assessments of digital agriculture, there is a risk of over-focusing the discussion on non-existent rural worlds, using imagined scenarios. Meanwhile, a process of digitalization is unfolding through everyday localized cultural and material processes on farms. Drawing upon a relational perspective, we present evidence of the need to replace notions of immutability, universality and uniformity, with the recognition of multiple ideas of development and the role of technologies in personal and collective development. This is a process in which this paper contributes only a small part to the mosaic, and we make a call of reflecting on generalization impulses. Heterogeneity can even occur at local levels, opening the space for multiple co-existing innovation processes. Embracing these notions of multiplicity can make digital innovation a more inclusive and contextualized system, and thus contribute to reducing reality-design gaps. Digital agriculture is a multi-faceted process occurring at different scales and towards different trajectories. A commendable goal is to

contribute to making it compatible with the life that farmers want to live. As we accounted, rural communities are actively involved in this process already; it is a matter of paying closer attention.

## 4.7. References

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## 5. Discussion

### 5.1. Evidence of the three studies at the light of the general conceptual framework

Despite digital agriculture can transform the face of agricultural systems, it is not yet clear in what way. To deal with this uncertainty, holistic perspectives on its consequences are necessary. In this regard, literature identified various areas that are still poorly explored, such as transition pathways (Klerkx et al., 2019) and local forms of digitalization (Rose et al., 2018; Rose & Chilvers, 2018). To address these knowledge gaps, this thesis examined socio-environmental consequences of digital agriculture and local processes of appropriation following a critical system approach based on the concepts of socio-technical systems, Responsible Innovation (RI), and Sen's Capabilities Approach (CA).

Technological innovation has been conceptualized as a socio-technical system (Bijker, 1999; Hughes, 1987; Klerkx et al., 2019; Zheng & Yu, 2016). Technologies are developed, deployed, and used characteristically according to the social context, namely the existing structural cultural, political, economic, and knowledge systems from where technologies emerge (Hellström, 2003; Zuboff, 1988). Simultaneously, the process transforms these same systems through the social and technical affordances of technologies and the forms of techno-governance to regulate the innovation process. A set of consequences derive from this process of co-construction. One of these refers to the agency of technology developers and promoters and their possibility of influencing society through the proposed technological assemblages (technologies rarely act in isolation from other technologies), and the approach to using them for solving societal problems. A second consequence is the influence of dominant development discourses on shaping the innovation trajectory. A third consequence is the possibility of differentiated social structures stemming from specific technological assemblages. For example, Winner (1980) expressed that authoritarian or democratic political systems can emerge from differentiated technologies and their technical characteristics.

Technical attributes of technologies are products of design decisions made by developers, which in turn are influenced by the socio-material context in which developers live and by their pre-existing knowledge. According to Gidley (2017), dreams and imaginaries influence innovations, which in turn, shape human actions and future scenarios. In tandem, it has been expressed that technologies embody the values of their developers (Bronson, 2018; Friedman & Kahn, 2002). Certainly, particular development discourses are institutionalized, influencing innovation trajectories and the direction of social change (Hayes & Westrup, 2012). For example, critical literature expressed that productivist, technocentric, and capitalist perspectives

strongly shape the narratives and practice of digital agriculture (Bronson and Knezevic, 2016; Bronson, 2018; Rotz *et al.*, 2019; Clapp and Ruder, 2020; Kuch, Kearnes and Gulson, 2020; Lajoie-O'Malley *et al.*, 2020). Following these perspectives, the trajectory proposed by influential developers and promoters of these technologies supports the maintenance of the status quo of unsustainable food production, while neglecting more agroecological perspectives (Bronson, 2019; Carbonell, 2016; Clapp & Ruder, 2020; Lajoie-O'Malley *et al.*, 2020; Wolf & Wood, 1997). Meanwhile, necessary changes to structural social injustice (Lajoie-O'Malley *et al.*, 2020), and local worldviews (Béguin *et al.*, 2012; Zheng, 2009) are hardly represented in mainstream digitalization agendas.

Numerous findings in this thesis support these ideas. For example, the analysis of 20 digital tools for the coffee value chain (CVC) identified that the knowledge and value systems associated with advisory services (especially tools for automated analysis of information such as AI and computer models) are strongly coupled with productivist approaches to agriculture. Despite the environmentalist rhetoric of the developers of these technologies, the practices promoted through these tools are still rooted in an industrial chemical-dependent form of production. The orientation of these advisory tools is to produce coffee to answer demands for a commoditized product, detached from social and environmental concerns and accountability. Meanwhile, non-production goals (e.g. knowledge co-creation, food sovereignty, increased participation and empowerment of rural communities), agroecological models, and practices for adaptation and the mitigation of climate change are overlooked in these tools. This in spite that social imbalances, high environmental footprint, and vulnerability to climate change have been highlighted as critical challenges for the sustainability of the CVC (Grabs, 2017; Läderach *et al.*, 2017; Panhuysen & Pierrot, 2020; Perfecto & Vandermeer, 2015; Sachs *et al.*, 2019). The research with coffee growing communities in Colombia (Chapter 4) identified an institutional innovation program associated with unquestioned quests for technification and industrialization. In this case, the institutionality represented by the Federación Nacional de Cafeteros (FNC), which in the past has promoted production based on chemical inputs and monocultures, failed to interpret the biophysical and cultural context when promoting a tool to mechanize the harvest. In this case, the traditional top-bottom model of knowledge transfer and the neglect of farmer's pre-existing knowledge affected perceptions and attitudes of local communities towards emerging technologies such as drones and robots.

There is however another part to this story. Undoubtedly developers of technologies have a strong influence on the trajectory of innovations. At the same time, developers are highly influenced by the context in which they are embedded and the development discourses, approaches to sustainability, personal experiences, and their acquired knowledge. This dynamic is well presented in critical studies on digital agriculture. Yet, other evidence in this thesis highlights the risk of critical literature falling into deterministic descriptions

(prescriptions?) of innovation, with their explanation of socio-technical change prominently overlooking a fundamental element: the agency of farmers. In connection with the theory of social construction of technologies (Bijker, 1999; Hughes, 1987; Orlikowski, 1992b), the agency of farmers and other potential users of digital technologies provides them the possibility to also shape the innovation process, to contest authoritarian socio-technical projects, and to create unforeseeable and multi-faceted trajectories. Additionally, contrasting with the common representation of developers as a monolithic and undisputable group of actors presented in critical literature, developers of digital technologies are not a homogeneous group, and their perspectives can also be multi-faceted.

Critical studies on digital agriculture commonly portray a dystopic future ruled by monopolistic corporate power. A future that is irrevocable and seemingly very stable. There are good reasons for these concerns. Corporations are very influential players, and their visions influence the social imaginaries of large segments of society. At the same time, the same techno-centric and productivist visions held by corporations are institutionalized through the work of highly influential organizations. This is what Lajoie-O'Malley et al. (2020) analyzed in the case of the World Bank, the Organization for Economic Cooperation and Development (OECD), and the Food and Agricultural Organization of the United Nations (FAO). However, technologies are co-created by numerous actors. In this process, users through use, assigned meaning, adaptation, and rejection, also play a pivotal role in the way the innovation process unfolds. This is an idea originated in the theory of social construction of technologies (see Orlikowski 1992; Bijker 1999; Hughes 1987).

To recap, the theory of social construction of technologies describes that technologies are physically and analytically constructed through social interactions and political choices of human actors (Orlikowski, 1992b). In resonance, Feenberg (1999) argues that users make creative appropriation by “reinventing devices through innovative applications” (p. 121). According to Béguin et al. (2012), a design process should always account for the fact that users do not act as the designers had planned and they enroll in learning processes to make the most of the technology according to their views and needs. In the book “How users matter. The Co-Construction of Users and Technology”, Oudshoorn and Pinch (2005) argue that there is no distinctive “correct” use of a technology, given that users decide on different forms of use based on their preferences. The exploration of political dynamics in digital agriculture from an emancipatory perspective - derived from Sen’s, Freire’s and Fals Bordas’s notions of sovereignty and agency (Chapter 2) - shows that digitalization can support exploitative and authoritarian forms of innovation. However, under different political and economic systems, digital technologies can be used to cast more democratic forms of innovation, even as tools for fighting oppression. By applying a capabilities approach, it was demonstrated how Colombian coffee growers exercised their agency to simultaneously reject and appropriate certain

aspects of digital technologies when integrating them into their life projects, farms, and social interactions. On the one hand, institutionality proposed an innovation (the harvesting machine), which farmers observed, analyzed, and decided not to buy. On the other hand, mainstream corporate imaginaries of digitalization dream of peopleless agricultural landscapes populated by swarms of automated artifacts. Through their description of a valuable life and ‘good’ farming, coffee-growing communities contested this vision, presenting in turn their proposition: a relational agriculture where digital technologies are used to nurture the social fabric of their communities. In agreement with the capabilities approach and its idea that multiple notions of development are possible (A. Jiménez & Zheng, 2018), this thesis presents evidence that in the process of technological appropriation, local perspectives of development are key in shaping users’ decisions around technologies. In this case, farmers’ agency is expressed by their capacity to position technologies in or out of the farm following the quest of living the life they value, and by their critical view which results in following an appropriation pathway divergent from dominant imaginaries and discourses around digital agriculture.

This research also shows that developers of digital technologies are a diverse group, holding a different set of values and development discourses. For example, while digital advisory services for the CVC predominantly represent a productivist perspective, digital tools to facilitate access to markets (digital platforms and traceability systems) follow a relational model, where the most important element is the connection and cooperation between diverse actors in the value chain. Evidence of this thesis points out that critical studies on digital agriculture will benefit from integrating the notion of farmers’ agency, which can be articulated through the concept of social construction of technologies. Additionally, this literature can integrate the CA to embrace the idea that, despite the evidence of a dominant development model in mainstream narratives and practice around digital agriculture, the scenario of digitalization is open for multiple development notions and trajectories, especially if local scales are considered. This level of analysis is aligned with the inclusionary principle of Responsible Innovation.

Although farmers’ agency must be accounted for as a key element in technological innovation, it has also been expressed that there are social and material constraints to this agency, and that non-cultural elements contribute to shaping it. In other words, it can be argued that farmers’ agency results from the negotiation with the agency of other human agents and non-human agents (land, plants, animals, technologies). Winner (1980) warned about the risk of reducing everything to social forces when it comes to explaining the social appropriation of technologies, a notion referred to by the author as the social determination of technology, which keeps a strong association with the concept of socio-technical systems and the theory of social construction of technologies. Winner (1980) argues that the technical characteristics of artifacts are important drivers of appropriation, and political phenomena in their own right. The argument is that these

characteristics greatly define the material and political (power relationships) affordances that technologies make available to society. This notion is very important for examining processes of technological innovation. For example, the analysis of digital tools for the coffee sector presented in this thesis shows that technical characteristics (functionality, technologies included, operation rules, information flow) strongly define the potential pathways towards sustainability that these tools endorse, and the ones they do not, for the CVC.

However, it would be misleading to indelibly link certain technologies with specific political structures. Winner (1980) also highlighted this when expressing that there are technologies that can be relatively flexible in design and can produce different societal consequences according to the setting where they are developed and deployed. For example, the same technology may present different consequences according to the diverse uses that can be given to it and the different contexts where they are used. Moreover, because agricultural digital tools are mostly assemblages of dissimilar digital technologies, it would be problematic to link tools to specific political relationships. The findings of this thesis corroborate this. The review on the political effects of digital agriculture (Chapter 2) identified that GPS technology and drones can be used to improve farm management and land planning. However, they can also be used for surveillance and data extractivism. Blockchain technology can be used to increase transparency in agricultural value chains. At the same time, it can represent a form of algorithmic authority with little connection to fairness and democratic decision-making. Smartphones can be used to receive agricultural recommendations from algorithms, while the study in Colombia showed that farmers prefer to use them to enable communications with family and the community (Chapter 4). Overall, this thesis demonstrates that, according to the way they are used and controlled, certain digital technologies can increase the agency of farmers, techno-barons, or cyber-agents. In fact, these three possibilities exist simultaneously. Moreover, this thesis supports the idea that digital agriculture is far from being a homogeneous technological category. Evidence of this thesis demonstrates that digital agriculture is formed by a very heterogeneous group of technologies with diverse technical characteristics and societal consequences. Different sets of technologies build differentiated pathways towards sustainability of the CVC (advisory services versus market access platforms) (Chapter 2). Smartphones and harvesting robots are ordered by Colombian coffee growers in a very contrasting way, both in their farms and imaginaries (Chapter 4). Literature, on the other hand, often represents digital agriculture as a uniform category, without reflecting much on the nuances occurring by the existence of very dissimilar technologies grouped under the same phenomenon.

Farmers' agency is also shaped by their material reality and knowledge. Central to the concept of digital gap is the idea that farmers experience restrictions to access equipment, technological infrastructure, and knowledge (Kritikos, 2017; Mehrabi et al., 2020; Seyedsayamdost & Vanderwal, 2020). These restrictions,

in turn, hinder the effective use of digital technologies by farmers and create hierarchies among them and with other actors of agricultural value chains who may have greater access to technologies and knowledge. It has also been reported that the physical complexity of agricultural landscapes is a barrier to using certain technologies such as smart tractors and harvesting robots (Legun & Burch, 2021). The results from the study with coffee growing communities in Colombia corroborate this. Farmers continuously reported how the harvesting machine promoted by the FNC and harvesting robots are not suitable for operating in the physical heterogeneity of coffee plots. The analysis of digital tools for the CVC found that access barriers to technologies result in processes of technical and knowledge hierarchies. For example, more marginalized producers are more likely to receive generic information for commodity production, while better-off producers have greater possibilities of receiving tailored information and participating in high-value digital markets. On the other hand, once again it is demonstrated that farmers are not passive actors in innovation. They actively implement strategies to work around these constraints to achieve their goals. The concept of 'tinkering' (Higgins et al., 2017) is useful for understanding how farmers navigate technical and biophysical constraints in the process of caring for their farm and life projects. In this process, local values are key drivers of this tinkering process. Using a capabilities approach, the research in Colombia revealed that socio-relational goals strongly motivate coffee households to work around economic and technical constraints such as connectivity and costs of devices in order to maintain communications with family and the community, and to support education processes of their children.

The interdependence between farmers' agency, material context, and broader social structures has been well explained in relational approaches in rural sociology (Darnhofer, 2020; Higgins, 2006). This approach has also been effective in discussing the agentic capacity of non-humans in the processes of farm transformation and of becoming a farmer, and to unpack the opportunity structure that build farmer's capabilities in the context of digitalization. With the exploration of a local process of digitalization in the Colombian context (Chapter 4), it was possible to identify that technological appropriation in the farm is a process of agency co-construction through multiple and localized interactions between knowledge, value systems, social institutions, and the agency of non-humans (land, plants, animals, technologies), in the search for integrating technologies into the life that farmers find valuable.

Building upon the notion of non-human agents, Forney and Dwiartama (2023) conceptualize digital agriculture as an interaction in assemblages of farmers, fields, machinery, advisors, science, and market relationships (among others), introducing new elements to this assemblage: databases and algorithms. Precisely, the analysis of political relationships in digital agriculture conducted in Chapter 2 shows that algorithms, smart artifacts, and automated machines, described in this thesis as cyber-agents, are novel actors in the innovation system. These technologies can act autonomously in the physical and cyber worlds,

transforming them, and being transformed by them. Also transforming not only interactions between humans and technologies, but also interactions between social actors, and between humans and non-humans (land, plants, animals). This network of interactions is what makes digital agriculture not merely a socio-technical system, but truly a socio-technical-physical system. Rijswijk et al. (2021) describe digitalization as a hybrid socio-cyber-physical system. Pointing out that digital technologies expand the world of artifacts through their potential action in cyber-space, while still accounting for the interaction of these technologies with biological and physical entities. This notion is highly relevant for a system approach in studies on digital agriculture. However, to my understanding, the term “cyber” in Rijswijk’s et al. definition obscures the fact that digital technologies can be both physical and cyber. For this reason, through this thesis, I propose the term ‘socio-technical-physical’ to capture the multiple dimensions of digital agriculture.

A key element of the relational approach in agricultural studies is the idea of farms as entities with agentic capacity, lively and affective (Darnhofer, 2020). In resonance, Layman and Civita (2022) found that relational Black, Indigenous, and People of Color (BIPOC) farmers in the USA described how their farming practice includes social relationships, together with “relationships with the land and the other-than-humans that inhabit agricultural spaces, including spirits, plants, animals, rocks, and more” (p. 975). According to the authors, close interactions with the land create unique relationships, empathy, and awareness of the farm as a living entity with the capacity to feel pain. The findings in this thesis show that the communities of coffee growers in Colombia share similar ideas. Learning from the land, enjoyment of direct contact with the farm and its elements, and the pride of learning through direct experience, create distinctive local forms of appropriation of digital technologies. To some respondents, coffee plants can be affectively affected by interactions with humans, machines, and other plants, influencing the position that farmers assign to digital technologies on the farm and the farming practice. Farming is relational, in addition, there are relational farmers - ones who act with awareness of relational processes on the farm. More than an instinctive awareness, responses from the interviews in Colombia illustrate that this existing notion of ‘sentient farms’, is built through the story of direct interaction with land and the stock of local knowledge. In contrast, mainstream digital agriculture can emerge from non-agricultural worlds and is not necessarily directed by situated experience. Additionally, mainstream digitalization often overlooks local perspectives (Rose and Chilvers 2018; Eastwood et al. 2019). For these reasons, the complex web of socio-technical-physical interactions is not necessarily acknowledged at broad-mainstream levels. As a consequence, the relational approach can be easily overlooked and neglected by the proponents of this form of mainstream digitalization.

The evidence from this thesis confirms that relational and emancipatory approaches to digitalization are present in grassroots communities with direct experience of farming and farms. This is the case of networked

freemen (digital communities of farmers organized in open-collaborative networks) presented in Chapter 2 and the case of Colombian coffee growers presented in Chapter 4. Meanwhile, despite the multiplicity of developers and proponents of digital technologies, it is striking to see how a rational linear approach is predominantly represented by mainstream and institutional digitalization (e.g. agrifood corporations, startups, and research centers). Although relational models are also represented, for example, in digital marketplaces and traceability systems, I found evidence that these platforms continue to operate under centralized control of infrastructure, unbalanced trade relationships, and asymmetric participation. These conditions are incompatible with relational-reciprocal forms of farming and emancipatory practices observed at local levels (Chapter 4) and in the post-capitalistic networks described in Chapter 2.

A lack of understanding and inclusion of local perspectives and the use of narrow and generic perspectives of development can explain the reality-design gap reported in the literature (Contreras-Medina et al., 2020; C. Eastwood et al., 2019; Heeks, 2002; Prost et al., 2012; Rose et al., 2018) and evidenced in the local case presented in Chapter 4. It also explains why mainstream digitalization imaginaries and practices can radically contrast with the farm-level processes of digitalization that result from localized associations between farmers, farms, and machines.

## **5.2. Contributions to the literature**

Critical literature presents a substantial contribution for examining digital agriculture from a RI lens. This body of literature has contested the neutrality of technological innovation and exposed the potential unwanted and unintended consequences of digital agriculture. However, critical literature on digital agriculture very often neglects the agency of users, their role in driving the innovation process, and their possibility to challenge authoritarian digitalization agendas and projects. This thesis demonstrates that integrating the concept of social construction of technologies into critical studies enables research to extend the understanding of digital agriculture. By transitioning from a deterministic to an agent-based perspective, this integrated approach can be better suited to describe the complex and dynamic web of interactions between social, technical, and physical systems that enables the coexistence of multiple innovation pathways. This possibility includes the creation of something new every time and everywhere through acts of planned and unplanned co-creation, even something emancipatory.

However, the concept of social construction of technologies can fall into a cultural determinism, neglecting the role of broader social structures and material limitations to the agency of farmers. For example, biophysical, technical, and knowledge factors that influence and constrain the action of farmers. The future is not so determined and dystopic, and the trajectory towards it is not as straightforward as critical studies

portray. Neither is the process strictly driven by cultural factors and messy interactions as the theory of social construction of technologies describes. Each line of argument provides relevant insights to understand the process of digital innovation. However, each one needs to integrate additional dimensions to fully grasp the complexity of the said process. This research shows that linking a relational approach to the concept of social construction of technologies allows research to integrate socio-material structural elements and the agency of non-human agents. In terms of digitalization, this integrated approach is very relevant for unpacking the interactions between disruptive technologies such as smart devices, algorithms, and automated machines, with social and biophysical systems. Thus, contributing to building a conceptualization of digital agriculture as a socio-technical-physical system.

Responding to the principles of inclusiveness and multiplicity of RI, the use of Sen's capabilities approach in the context of digital agriculture has proven to be useful to explore the multiple ideas of development and diverse perspectives of a desired future and the way digital technologies fit in this vision. This approach allowed me to identify the tractions and frictions between diverse perspectives in the multi-stakeholder scenario that characterizes digital agriculture. This understanding highlighted reality-design gaps and revealed the critical view of farmers, questioning the generalized concepts of 'adoption' and 'development'.

Digital agriculture is commonly described in critical studies as a homogeneous category, with shared technical characteristics, and general societal and environmental consequences. This representation eclipses the fact that digital agriculture is composed of a wide diversity of technologies, each with specific technical attributes, affordances, and forms of socio-technical-physical interaction. A close look at different technological assemblages and varied technical attributes presented in chapter 3 provided a more nuanced perspective on digitalization in the CVC, contributing with this nuanced description to the general debate on the role of digital technologies in the sustainability of agricultural systems. Incorporating material and symbolic interactions in the coffee farming system in the Colombian context allowed this research to develop a discriminated discussion of digital technologies. The findings suggest that dissimilar technologies (e.g. communication tools and robots) are differently positioned in farms, farming, social relations, and local imaginaries. These results support the idea that the study of digital agriculture needs to be conducted with consideration of its diversity of technologies, technical attributes, and societal and environmental consequences.

### **5.3. Policy recommendations**

Digital technologies have the potential to facilitate the transition of agriculture towards more sustainable models and agricultural practices. Currently, the mainstream agenda and practice of digital agriculture is

based on a narrow set of values, production models, and perspectives of development. Responsible digital innovation in agriculture calls for a broader scope of social and environmental considerations. Digital tools need to be developed with the incorporation of diverse production models, including more agroecological and relational approaches. It is necessary to place a stronger emphasis on the participation of producers in technological development and benefits distribution. This can be achieved through new opportunities to participate in important decisions related to functionality and technical attributes and in the social distribution of value, access, and knowledge. Additionally, the process calls for strong ethical considerations, including the responsible management of digital data from users and the protection of human rights such as sovereignty, privacy, and access to complete information. Policies and industrial practices need to address these issues more seriously.

Far from linear diffusion trajectories, digital agriculture occurs within a complex web of interactions between social, technical, and biophysical systems. In processes of digital innovation, following a relational approach that accounts for this complexity can result in the development of more inclusive and contextualized digital tools. In congruence with the complexity of technological innovation, it is necessary to recognize and respect the multiple social ideas of development (from a capabilities perspective) and forms of technological appropriation. Embracing multiplicity requires abandoning notions of immutability, universality, and uniformity in development discourses, perspectives of rurality, and the generation of new technologies. Responsible innovation calls for this inclusionary and reflexive perspective.

It is demonstrated that certain political and economic structures engender certain digitalization trajectories. These can be authoritarian, exploitative, and unsustainable, or democratic, emancipatory, and socially and environmentally responsible. To be truly revolutionary, beyond technical fixes that do not transform structural inequalities and unsustainable production models, digital agriculture calls for new political, economic, and ecological relationships. Co-creating digital technologies that work for people and the planet requires to embrace modes of thinking, being, and acting based on cooperation, solidarity, and respect - respect for human rights, alternative worldviews, and the well-being of non-humans.

#### **5.4. Limitations of the study**

Although the thesis presents a series of relevant insights to understand digital agriculture from a critical and systems perspective, it does not come without a series of limitations that can hinder a more meaningful contribution to theory and policy, opening avenues for further inquiries and corroborations.

Although the theoretical literature review conducted in chapter 2 is methodologically sound with the grounded theory approach adopted in this thesis, it entails some drawbacks. First, in a non-systematic

literature review, the selection of literature is open to subjective choices which can introduce bias. For example, following a snowball theoretical sampling literature review method for this paper resulted in an initial over-representation of political and ethical analysis around precision agriculture and big data in agriculture, which is only one component of digital agriculture. Without awareness of this situation, other forms of digitalization, less explored in critical literature, such as smallholder digital agriculture and digital communities of practice, could go unexamined. To avoid this situation, I included focused searches for political analysis of smallholder digital agriculture and applied the knowledge acquired on digital tools for the CVC, a constellation which is not part of precision agriculture or big data. Nevertheless, political analyses that do not correspond to precision agriculture and big data are systematically underrepresented in critical literature and obtained less attention in public debates on the politics of digital agriculture (a gap that I tried to address through my research with coffee growers in Colombia). To present a more comprehensive perspective, I also followed the line in the literature that deals with contrasting forms of digital agriculture such as open-source software, data cooperatives, grassroots-based digital communities, and digital activism. This search allowed this thesis to present a different side of digitalization. This alternative view, namely, the emancipatory pathway of digitalization, has been less discussed in the literature. However, it was possible to identify valuable examples. Second, a non-systematic literature review is difficult to reproduce, leaving the findings and conclusions predominantly resting on the insights of the authors (Egger et al., 2001). One remedy applied in this thesis was to approach the literature review with open-mind and impartiality to include all types of evidence and discussions. Although the methodology cannot be easily reproduced, the analysis presented is exhaustive and inclusive with the most current debates around the political dynamics of digital agriculture. Additionally, the analysis presented in chapter 2 is supported by an extensive review of sources, integrated by more than 300 full-text consulted sources at the moment of submitting the paper. Nevertheless, it is advisable to conduct systematic literature reviews in the area of politics of digital agriculture, especially reviews oriented towards unveiling these dynamics in the ambit of smallholder digitalization and beyond big-tech digitalization.

A comprehensive review of digital tools for the CVC is presented in chapter 3. This examination allowed this thesis to identify two different pathways towards sustainability and describe the varying opportunities and challenges for agricultural development associated with these pathways. This examination was only focused on two types of tools (advisory services and tools for accessing markets, inputs, and services), leaving out other types of digital tools. This included digital transactions, and accounting and financial management tools. Additionally, the analysis was focused on the production stage of the CVC, although it is well-known that digital technologies are also developed and implemented in other stages, such as transportation, transformation, trade, and consumption. For these reasons, a socio-technical examination that includes these additional types of digital tools and other stages of the value chain can provide a more

comprehensive view of digitalization pathways of the CVC, its consequences for the sustainability of the value chain, and identify additional opportunities and challenges for agricultural development. Furthermore, the ecosystem of digital innovation is highly dynamic. New tools emerge every day and others are dismantled, creating an ever-changing scenario of digitalization of the CVC. The description provided in this thesis corresponds to a specific point in time that potentially has changed since the time the analysis was conducted. This calls for new examinations that can capture the evolution of the process over time, catching up with new developments and dynamics. However, it is important to understand that value systems and power structures driving this process are more stable and changes at this level occur at a slower pace.

Two communities of Colombian coffee growers were selected in chapter 4 to explore local interactions with technologies. By focusing on geographical variation (Caribbean and Andean regions) and integrating different forms of production (conventional and organic), the thesis aimed to present an inclusive analysis of the phenomenon and provide a nuanced discussion of local digitalization processes in the Colombian context. The findings suggest that similar views are shared across geographies and production systems, while the variations occur rather within the same communities. Nevertheless, given the limited scope of the study, together with the occurrence of localized socio-technical-physical interactions, it is discouraged to fall into generalizations when describing digitalization in communities of coffee growers. A capabilities approach applied with other communities in Colombia, and other producing countries, can reveal additional forms of interaction with digital technologies and the diverse socio-technical-physical local assemblages that produce them. Precisely, a relevant suggestion from this chapter is to embrace a sense of multiplicity, not only when designing digital tools, but also when studying them.

## **5.5. Concluding remarks**

By applying a critical lens to digital agriculture and focusing on the coffee system, this thesis provides a systems understanding of socio-technical-physical interactions that lead to broad-mainstream and local-everyday innovation pathways. These pathways were analyzed from a cultural and political perspective in particular.

Digital agriculture is not a homogeneous category but a highly diverse group of technologies and technological assemblages. Each one presents characteristic socio-technical affordances, inclusion-exclusion dynamics (social and ontological), and produces particular social and environmental consequences. It is important to consider this heterogeneity when approaching the study of digital agriculture and to conduct nuanced analyses embracing technical heterogeneity.

Developers and proponents of agricultural digital technologies play a key role in the innovation process. A configuration that showed strong patterns of dominance and centralization, both in worldviews and influence. However, technologies are socially constructed, meaning that users are rarely passive actors. Users always have forms of agency, levels of influence, and possibilities to contest authoritarian innovation trajectories through creative appropriation. However, this does not mean that developers should remain unaccountable for unethical, opportunistic, and exploitative behaviors and that regulatory frames should not be implemented to prevent these behaviors. Value systems (including development perspectives) are a key element of technological innovation. While developers' values contribute to shaping how technologies are designed and deployed, users' values contribute to defining how these technologies are appropriated. This appropriation includes practices of signification, adaptation, rejection, and reconfiguration, in the quest for integrating technologies with the life users find valuable. Understanding what constitutes a valuable life in different user's context can support the development of more inclusive digital tools and the reduction of reality-design gaps. This understanding can also support the recognition of contexts where digitalization is not the desired pathway. The capabilities approach has proved to be a very effective framework to acquire a good understanding of contextualized valuable lives. This is particularly relevant in digital agriculture as these technologies are commonly conceived and developed from non-existent rural worlds or non-rural worlds, and not always informed by experience.

Digital agriculture is a socio-technical-physical system, where farmers' agency applied to technological appropriation results from multiple negotiations with the agency of other humans and non-humans. On the one hand, digitalization brings a new group of agents with capacity to act in the cyber and the material world. This group is formed by smart devices, algorithms, and automated machines - described in this thesis as cyber-agents – who act materially and regulatively over agricultural systems and across agrifood value chains. In many cases, they do so without human mediation and with society not having a clear understanding of their reasoning. On the other hand, relational approaches evidenced in local appropriation processes and farming practices – and resonant with current approaches in rural sociology - reveal the agentic capacity of farms, plants, and animals, and the role of this agentic capacity in the process of digitalization in rural settings. The biophysical attributes of these entities set certain limits to the design, development, and use of digital technologies. Meanwhile, the affectivity and liveliness of these elements play a role in the way farmers order digital technologies within their farms and imaginaries. In some cases, this means placing these technologies outside their plots and agricultural practices to not interfere with relations of reciprocity and care.

Social structures (social, political, and economic systems), and the institutions they engender, influence the way technologies are developed, deployed, and used. Authoritarian and exploitative social systems engender

digital technologies that reproduce and deepen these structures. This dynamic occurs with serious consequences for the sovereignty and agency of farmers. This trajectory includes productivist, extractivist, profit-oriented, and corporate-locked forms of digitalization. On the other hand, social structures configured around democratic and solidarity values, and that follow ethical principles (social and planetary), with respect for human rights and dignity, can engender more open, emancipatory, and holistic digitalization models. In the frame of structural injustice (within social groups and with the planet) that characterizes the current agricultural system, this latter pathway embodies the truly revolutionary potential of digital agriculture.

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