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Searching for sustainability in the digital agriculture debate: an alternative approach for a systemic transition[1]

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Abstract. One of the key challenges for agriculture today is feeding an increasing population without contributing to climate change. Increasingly, digital agriculture is discussed as a new sociotechnical regime that could help limit emissions for farmers worldwide. While sustainability is an important issue, recent papers in the field of digital agriculture do not address the problem directly. After a literature review, this paper will focus on the importance of shared perspectives as enablers in socio-technical transitions. This paper argues that the myth of the digital sublime could act in favour of the existing and unsustainable model of agriculture. This is partly a result of hardware production and connectivity already being resource-intensive. Precisely because of this high environmental impact, the following discussion will employ the legacy of the Green Revolution to highlight the importance of precaution in deploying digital agriculture. In theory, in order to address the shortcomings of the current system, private sector companies are developing proprietary software solutions that could in practice entrench unsustainable business models. As an alternative, this paper suggests, existing open-source platforms that encourage not-for-profit collaborations between farmers should be scaled up. Through bottom-up processes, future researchers and developers should seek ways to place sustainability at the centre of their analyses, and encourage the adoption of practices that can be tailored to the diverse needs of farmers. Ultimately, stakeholders in digital agriculture should understand that sustainability principles must be encoded at all stages in the deployment of digital agriculture technologies.
Keywords: climate change; digital sublime; green revolution; open-source software; socio-technical regime.

[es] Buscando la sostenibilidad en el debate sobre agricultura digital: un enfoque alternativo para la transición sistémica

Resumen. Uno de los desafíos principales para la agricultura contemporánea es alimentar a una población creciente sin contribuir al cambio climático. En tiempos recientes, la agricultura digital es un nuevo régimen sociotécnico que podría ayudar a granjeros de todo el mundo a reducir emisiones. Aunque la sostenibilidad es un asunto importante, artículos recientes en el campo de la agricultura digital no se dedican al problema directamente. Tras una revisión de la literatura, este artículo se centrará en la importancia de las perspectivas compartidas como facilitadores de transiciones sociotécnicas. Este artículo propone que el mito de lo sublime digital podría actuar a favor del actual e insostenible modelo agrícola. Esto es en parte el resultado de que la producción de hardware y la conectividad ya consuman muchos recursos. Precisamente como resultado de este alto impacto medioambiental, la discusión posterior empleará el legado de la Revolución Verde para subrayar la importancia de la precaución ante el desarrollo de la agricultura digital. Teóricamente para subsanar los problemas del sistema actual, compañías privadas están desarrollando soluciones basadas en software patentado que podrían en la práctica sostener prácticas insostenibles. Como alternativa, este artículo sugiere reforzar el papel de plataformas abiertas que promueven colaboraciones sin ánimo de lucro entre granjeros. A través de procesos de abajo a arriba, futuros investigadores y desarrolladores deberían buscar maneras de colocar la sostenibilidad en el centro de sus análisis y promover actividades que puedan adaptarse a las necesidades diversas de los granjeros. En última instancia, los participantes de la agricultura digital deberán entender que los principios de sostenibilidad habrán de ser programados en cada etapa de desarrollo de tecnologías de agricultura digital.
Palabras clave: cambio climático; régimen sociotécnico; revolución verde; software abierto; sublime digital.

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1. Introduction

As described by Godfray et al. (2010), research conducted in first decade of the century concluded that there is a yield gap that needs to be met in order feed 9 billion people by 2050. These researchers recommended that public and private organisations increased their investment in agrarian innovation to meet these targets without compromising natural resources (Godfray et al., 2010). Almost a decade later, in 2019, the International Panel on Climate Change, which accounts for the latest technical knowledge on climate change risks, published its Climate Change and Land (SRCCL) paper, co-authored by Shukla et al. (2019). Written by 96 experts referencing more than 7000 works, the report describes how land use activities like agriculture and forestry are still responsible for more than a quarter of total anthropogenic greenhouse gas emissions. On the same report, the authors note how land plays a fundamental role in capturing carbon dioxide; thus, avoiding land degradation is an important priority (Shukla et al., 2019). As a result, on the summary for policymakers, the IPCC (2019) team connects the issue of climate change with actions to increase food security worldwide, and reduce food waste across the agricultural chain. This is because climate change is set to diminish yields as land quality decreases due to changing weather patterns (IPCC, 2019). According to the Science Advice for Policy by European Academies body (SAPEA), part of the European Commission's Scientific Advice Mechanism, the issue of environmental sustainability is also linked to social sustainability, as the degradation of food security is a core cause of poverty, economic instability, and conflict across the world. The solution is to pursue sustainable intensification, according to this scientific committee (SAPEA, 2020).

Sustainable intensification in agriculture is simply defined as the ability to produce more with less inputs. Increasingly, however, the term has become associated with the idea of a systemic transition towards agrarian systems that respect the Earth's environmental limits. Firbank et al. (2018) define the concept as the ability to achieve higher productivity in a just (meeting the United Nations Sustainable Development Goals) and safe way (respecting the environment and improving nutrition). Firbank et al. (2018) describe the different obstacles this transition is facing: selection of indicators, reluctance towards new business models, entrenchment of global value chains, urbanisation and diet sophistication. There is growing consensus that true systemic change will be necessary to achieve real sustainability. On this note, Bernard and Lux (2017) argue that a limited focus on increasing production, as defined by the traditional paradigm of industrial agriculture, has not been enough to obtain food security. At the same time, they quote criticisms from the United Nations Conference on Trade and Development (UNCTAD) which have noticed the lacklustre implementation of sustainability goals in agriculture despite the generalised adoption of global agendas (UNCTAD, 2013). Their conclusion is that agriculture research must start looking beyond productivity and broaden its view on the environmental impacts of the whole agricultural system (Bernard and Lux, 2017, p. 1288). Studies quoted by Firbank et al. (2018) agree with this holistic perspective, recommending global dietary changes (Tilman and Clark, 2014), large-scale interventions by global food retailers (Macfayden et al., 2015), the generalisation of organic agricultural practices in combination with dietary changes (Muller et al., 2017). Earlier, Williams (2011) even suggested that a complete overhaul of the world's approach to economic growth is needed. According to these scientists, sustainability's incompatibility with contemporary agriculture would require an entire rethinking of current agrarian ways of thinking and practices to achieve a positive outcome.

One particular combination of new perspectives and practices that is more and more promoted as a solution is 'digital agriculture'; also referred to by other terms by the papers on this review, such as 'smart agriculture', 'AgriTech', 'Agriculture 4.0 or digital precision agriculture*'*. The body responsible for coordinating global policies between the world's most important governments, the G20, recently called for the promotion of digital agriculture solutions to increase efficiency across the chain and tackle climate change (G20, 2017). Researchers at key development institutions, like Trendov et al. (2019) at the World Bank, are suggesting the promotion of technology start-ups in developing countries to address climate change in agriculture. This is echoed by projects from national development agencies, like the United States Agency for International Development, which funded projects like *Digital Development for Feed the Future* (USAID, 2017), seeking to extend precision 'agriculture', digital financial services, data-driven farming and digital extension services to the developing world. As reported by Mattison (2019) and CGIAR (2020), multi-stakeholder research bodies, like the Consultative Group on International Agricultural Research (CGIAR) or the Technical Centre for Agricultural and Rural Cooperation (CTA) are working towards big data-based decision applications that provide extension services for farmers. Relevant philanthropic organisations, like the Gates Foundation (2020), are also testing digital projects in rural areas. Khan (2018), working for the Rockefeller Foundation, argues that digital agriculture can generate the next Green Revolution (in reference to the last systemic transition in agriculture, discussed below). Finally, an important voice in the private sector, the World Economic Forum, in cooperation with Mc-Kinsey, has also published a report which identifies digital agriculture solutions as ideal tools to increase productivity, profitability and reduce poverty in rural areas (World Economic Forum and McKinsey, 2018).

Considering the urgent need to reconcile agrarian practices with our planetary limits, it is not surprising that agenda-setting organisations in international development, transnational agrarian research, philanthropy and the private sector are increasingly interested in digital innovations. Indeed, Trendov's (2019) World Bank study and the World Economic Forum and McKinsey's report (2018) show great potential for digital tools to address environmental issues identified by recent research: limiting the consumption of resources like water, maintaining soil quality, reducing food waste across chains and helping farmers adopt sustainable practices. This review paper does not dispute this potential. At the same time, as it will be understood through assessing key contributions to the field, it will argue that sustainability must be placed at the centre, for digital agriculture to mitigate and adapt to climate change. This is because the success of 'socio-technical' innovations is particularly vulnerable to narratives. There is a risk that a narrative influenced by the myth of the *digital sublime* will favour marginal solutions to a systemic issue. Rather, a systemic approach is fundamental to address the incompatibility between our current agrarian *socio-technical regime*, and the Earth's environmental limits. After explaining why this approach is necessary, the paper will advance some alternative solutions for future researchers to consider.

2. Review methodology and key research questions

The methodology for this review will follow the steps established by information system scholars Templier and Paré (2015): describing key questions and goals; summarising extant literature; evaluating the applicability of empirical studies; confirming the accuracy of primary studies; extracting key conclusions and synthesising them according to the research questions. This review has a traditional narrative style, focused on qualitative assessments as described by Sylvester et al. (2013). In the past, this methodology has been criticised because it can fall prey to author biases, as argued by Green et al. (2006); nonetheless, these reviews have significance as they attempt to demonstrate to future scholars the benefits of choosing a particular perspective on an issue (Baumeister and Leary, 1997). Green et al. (2006) also suggest that, if the research can overcome biases, narrative reviews can help faculty, students and future researchers identify key debates and fruitful paths for research. A solution from Paré and Kitsiou (2017) is to explicitly describe the space(s) where the literature search was conducted; the process of selection analysis; and the writing method (they cite as examples, among others, Levy and Ellis, 2006; vom Brocke et al. 2009; Bandara et al., 2011). In particular, they encourage scholars to follow the example of Darlow and Wen (2015), who carefully described their search method, criteria for inclusion and exclusion, and information extraction methods at the start of their paper.

Following these prescriptions, this review's methodology is as follows. First, this literature review is in the tradition of the fifth goal of knowledge syntheses described by Paré et al. (2015): identifying themes that require more investigation. Consequently, this review aims to assess the focus on sustainability of recent reviews in the sphere of digital agriculture politics/political economy; chiefly Bronson and Knezevic (2016), Carolan (2017), Wolfert et al. (2017), Klerkx et al. (2019), Rotz et al. (2019), and Klerkx and Rose (2020). A parallel goal for literature reviews, as described by Levy and Ellis (2006), is to suggest novel approaches to existing research themes. Thus, a second aim for this review is to evidence the importance of political ecology perspectives of 'socio-technical transition' to understand the deployment of digital agriculture. The author feels that most of these analyses would benefit from recognising the importance of sustainability discourses in framing the possibilities of 'socio-technical regime transitions'. As a critical point of departure, the review also proposes the deployment of the concept of the 'digital sublime', to contextualise and critically assess the assumptions dominating innovation today, and foreground the very materiality and possible ecological impact of connecting, sensoring and monitoring farms. In a way, this review aims to take to the macro-level the insights collected by Higgins and Bryant (2020) at the meso-level. Though on-site interviews with extension agents, farmers and other stakeholders, both authors identified how the different ways smart or digital farming was framed in rice-growing regions of Australia actually favoured the strategies of major industry actors over smaller agents (Higgins and Bryant, 2020, p. 453). On the global level, this paper argues that the narrative through which digital agriculture and sustainability are discussed and deployed will have effects on maintaining or changing the current 'socio-technical regime'.

The identification of key articles was conducted through Google Scholar, via its 'Related articles' and 'Cited by tools', through a method called 'snowballing', as described by Lecy and Beatty (2012). These tools also help identify the relationships between review articles published in the last half decade and other secondary and empirical research covering digital agriculture. Inclusion criteria were: the article had to be written in English; and the studies had to focus on the politics and political economy of digital agriculture. Exclusion criteria were: lack of focus on digital agriculture specifically; lack of focus on issues of political or economic power and inequalities; and lack of consideration with issues related to proprietary software technologies. Finally, information extraction was guided by the use of keywords referring to the research questions: 'agricultural technology and sustainability'; 'software and data ownership in farms'; 'information asymmetries across agrarian chains'; 'proprietary farming platforms'; 'open-source farming; and digital precision agriculture'. These key words for information extraction also guided the search of topics on Google Scholar and across reference lists. The examination of each piece of material found through this methodology focused on the basic assumptions, choice of empirical studies, and overall conclusion on the distributional (political and economic) consequences of agrarian digitalisation through proprietary software platforms. Some of the empirical works the review articles referred to included Bogaardt et al. (2016), Zhang (2016), Lindblom et al. (2016), Eastwood et al. (2017), Antle et al. (2017), Janssen et al. (2017), Lioutas and Charatsari (2020) and Salam (2020). Since this was an individual project, the author could not compare the results of this selection with a colleague. However, the methodology was developed in close collaboration with a research supervisor, and takes into account the comments of very helpful anonymous reviewers.

3. Theoretical framework: sustainable transitions and *socio-technical regime* narratives

The interdisciplinary field of transition studies has for long been concerned with the development of a more sustainable food system. As argued by Hinrichs (2014), the multifaceted nature of climate change means that social scientists must complement natural scientists and engineers in understanding a switch to sustainable alternatives. In her paper, Hinrichs (2014, pp. 145-146) documented how governments, civil society organisations and other bodies were increasingly interested in 'socio-technical transitions' as the template for understanding change towards more sustainable social and economic arrangements. This concept, borrowed from innovation studies, attempts to understand systemic shifts between 'socio-technical regimes' through the interactions between knowledge, tools and institutions, as explained by Farla et al. (2012). Rip and Kemp (1998) originally defined 'socio-technical regimes' as stable structures composed by products, technologies, knowledges, practices, expectations… Accordingly, as Markard and Truffer (2008) described, the regime also acts as a buffer for the diffusion of innovations; that is, it has a path-dependent inertia. One example these authors cite as is the conception of centralised power generation, which has determined the design of most electrical infrastructures employing both fossil fuels and renewable energies. At the same time, regime definitions depend, in their view, on the researcher's assumptions, perspectives or goals (Markard and Truffer, 2008). For example, Hinrichs (2014) argued that sustainable innovation scholars were too concerned with key hard technologies (wind turbines); while food system researchers assumed farm innovations would automatically perpetuate unsustainable models of industrial agriculture (Hinrichs, 2014:147). As a way of building bridges, she recommended researchers to examine issues of power, politics and governance and the discourses that ultimately determined the future of sustainable solutions in agriculture. How is sustainability defined by key actors and which solutions does it incorporate? How would an alternative future look like, if the seeds of an alternative 'socio-technical regime' were protected and nurtured by relevant actors?

Echoing the questions raised by Hinrichs, this review paper will question how sustainability is understood in relation to digital agriculture by examining seminal interventions in the field. Later, the paper will explain how these understandings could benefit from identifying the narratives that promote a 'socio-technical transition' to a more sustainable agrarian regime. This paper's overview follows the framework of key scholars cited by Hinrichs, that of Lawhon and Murphy (2012), and their application of political ecology to the study of 'socio-technical regimes' and transitions to sustainability. In particular, Lawhon and Murphy (2012, pp 369-370) use the example of genetically modified organisms (GMOs) to suggest how researchers can learn by examining the validity of elite claims regarding their ecological benefits. According to Lawhon and Murphy, it is important to understand which are the key narratives and counternarratives framing the deployment of agrarian innovation. In their conclusion, they invoke political ecology as an approach that analyses the inclusion/exclusion mechanisms operating in the context provided by 'socio-technical regimes' Lawhon and Murphy (2012, p. 371).

As a result, after analysing key articles, the initial focus of this review paper will be in understanding how the 'technological/digital sublime' is occluding practical issues of sustainability in the information and communication technology (ICT) sector. The paper will describe how the ecological impact of hardware production, its energy consumption and software models could threaten to act in favour of the existing 'socio-technical regime'; if researchers do not adopt a systemic perspective on sustainability. First, the review of recent interventions in the field by digital scholars is an attempt to clarify the role of sustainability in the digital realm.

4. Review of key papers in digital agriculture and the presence of sustainability in their assessment

The following papers grant a varying role to issues of sustainability and ecological transition in their discussion of digital agriculture. In chronological order, the first key paper in review is Bronson and Knezevic's (2016). This is a commentary that focuses on how the deployment of tools that capture, combine and study on-farm data can impact relationships across the value chain (defined by the authors as Big Data). The key ecological consequence Bronson and Knezevic (2016) identify is the enhanced role of 'productivism' as a farming model in proprietary software applications: the one that seeks to maximise outputs from technology; and has, according to studies cited by the authors, caused large socioecological distress across the world.

From the point of view of micro-politics, Carolan (2017) is interested in the growing role of alternative digital communities that are taking part in the governance of the agro-digital chain. With regard to ecology, he focuses on the paradox of technological devices, which are criticised by many food studies scholars as inherently opposed to sustainable farming. On the other hand, his research also shows that they are contributing to the creation of collectives like *Farm Hack*, which question the domination of large agribusiness of the digital agriculture sphere (Carolan, 2017, p. 830).

Wolfert et al. (2017) offer an agrarian systems perspective on possible consequences of digital applications across the value chain, by surveying more than 600 articles on the topic. Their framework focused on the employment of Big Data in farming processes, envisioning a value chain going from the data collected on farms, to farm management, to its application in farm processes. Above and around this layer, they observed the stakeholder network (farmers, buyers, consumers, input sellers) influencing agribusiness; and the network management sphere of organisations and technologies behind big data applications (Wolfert et al., 2017, p. 71). While they focus mostly on distributional issues across the chain, they also identify certain pull factors in their deployment which are linked to sustainability. In particular, they quote Lesser (2014), Gilpin (2015) and Poppe et al. (2015) on how food security and safety worldwide are pushing the deployment of digital farming. However, Wolfert et al. (2017) are not very concerned with accounting for the ecological costs and consequences of implementing digital systems in farming.

The interdisciplinary introduction by Klerkx et al. (2019) summarises ongoing interventions from the social sciences in the field of digital agriculture. The authors' goal is to identify papers around five key thematic clusters: adoption of digital technologies on the farm, impact of digitalisation on agrarian labour, power and privacy dynamics across chains, digitalisation of agrarian knowledge, and economics of digital value chains (Klerkx et al., 2019, p. 4). Sustainability or ecological concerns are not explicitly highlighted as perspectives; but included under the titles of *responsible research and innovation* and *farming styles*. They do mention certain works on the compatibility of agroecology with digital farming (Plumecocq et al., 2018 and Van Hulst et al., 2020); the development of circular economy platforms to limit waste (Miles and Smith, 2015, Galliano et al., 2017, Geissdoerfer et al., 2017); the importance of clear environmental targets for incentivising the application digital solutions for sustainability (Barnes et al., 2019); and Bronson's (2019) insights into the preferences for industrial agriculture of digital innovation designers. The conclusion to Klerkx et al.'s (2019) review is shaped through key future questions that researchers should address, but none of the more than a dozen suggestions directly refers to issues of sustainability and ecological adaptation in the farm.

From the perspective of political economy, Rotz et al. (2019) have written one of the latest reviews of the politics of digital agricultural technologies, covering three major challenges: ownership and management over data; manufacture of technologies and development; and data security. They use the encompassing term digital agriculture as a reference to both precision agriculture and big data applications. Rotz et al. (2019) justify their review on the basis that previous commentators, such as Bronson and Knezvic (2016); Carolan (2017); Chi et al. (2017) and Mooney and ETC (2018) have taken a sceptical view towards digitalisation, with regard to its possibilities to improve and environmental sustainability. As a result, Rotz et al. (2019, p. 205) seek to advance the discussion from the perspective of deploying digital technologies that can effectively address inequalities and environmental degradation; rather than taking for granted their mutual exclusivity with digitalisation. Rotz et al.'s (2019) approach is inspired by previous examinations of winners and losers as a result of innovations in global agriculture: what is the emerging relationship between farmers, agribusinesses, the state and other stakeholders? (cf. Friedmann, 1993; Fine et al., 1994; Clapp et al., 2017). Most of the papers Rotz et al. (2019) review, the authors note, coincide in their assertion that digital agriculture will contribute to further market and land concentration, smallholder exclusion and the perpetuation of the model of industrial agriculture. Their alternative proposition, which will also be commented in the conclusion, is that state-led efforts to invest in platforms and other technologies could actually avoid those risks. This is because, according to Rotz et al. (2019, p. 217) open-source software (they mention Farm Hack, FarmOS, ISOBlue, AgriLedger) can help small and medium-sized farmers generate more environmentally-friendly circuits of production and commercialisation. At the same time, they admit the limitations of these localised interventions, considering the current market power of agribusiness, and call other researchers to analyse the different sources of data (in) justice in agriculture (Rotz et al., 2019).

Finally, Klerkx and Rose (2020) describe Agriculture 4.0, which includes on-farm digital innovations, as the upcoming transition in the food system. However, they also advise against the risks of failing to consider issues of exclusion and inclusion in innovation systems; which are not neutral (something shared by this paper's theoretical framework). They identify several risks, such as: the reinforcement of technocratic and 'productivist' food system discourses; the side-lining of already existing and necessary but less capital-intensive tools; and the marginalisation of agroecology as a farming paradigm (Klerkx and Rose, 2020, pp. 2-4). While this would have an impact on sustainability, the concept itself is not addressed by Klerkx and Rose (2020). As a solution to exclusion challenges, both authors propose the creation of innovation systems and processes which allow all stakeholders to participate in the development of digital agriculture. Notably, in line with this review paper, their final words encourage researchers to explore the contradictions and connections between new technologies and stated goals like increased yields against successfully adapting to climate change (Klerkx and Rose, 2020, p. 5).

This brief overview of review articles in the sphere of digital agriculture incidentally covers the micro, meso and macro levels of 'socio-technical regime transition': from individuals, to firm strategies, and to global discourses on ITCs for farming. While many of them employ sustainability as background or justification for ongoing innovation, only Rotz et al. (2019) have an explicit section of their paper to discuss the political ecology of digital agriculture. The rest are more concerned with distributional effects across the value chain; something that will implicitly have effects on the environment, but not directly. Thus, while climate change and agricultural emissions are evoked as key issues for agriculture, they are not directly discussed in relation with what is purportedly the next great systemic transition in the sector. Echoing Klerkx and Rose's (2020) call, an important step in predicting how *Agriculture 4.0* at scale could look like should involve considering its potential effects on the environment. However, most current reviews ignore the latter. This review paper would like to advance a hypothesis on why this is the case, by employing the conceptual device of the 'technological/ digital sublime' and its important role in previous and future 'socio-technical regime transitions' in agriculture. The final section will summarise some ideas on how to include concerns about sustainability in the discussion of digital agriculture.

5. The role of the *digital sublime* in supporting unsustainable *socio-technical regimes*

Technological fetishism; that is, awarding special attributes to physical or virtual human creations, is not particularly new. At the turn of the century, Harvey (2003) described how many of us and our institutions mystify technology, in our daily practices or in academic research. According to the author, we sometimes practice a technological reductionism that associates certain effects with particular devices, especially hardware like computers or phones. Harvey (2003, pp. 7-11) linked this with contemporary capitalism's fixation with productivity, which places innovation as a privileged activity that should be prioritised; often, ignoring the very social relations that are necessary for technology to have any effect. Nevertheless, even if this causality is spurious, it does not mean that fetishism has no effect in guiding socioeconomic change. What Harvey called *mentalités* or ways of thinking associated with technologies still influence the way we ask questions and provide answers to problems like climate change. That is, it is not the technologies in themselves that determine certain effects. Rather, it is the *social relations and assumptions* that are embedded with those technologies which play an important role in structuring our thinking and actions (Harvey, 2003, p. 14).

In a similar vein, from the field of communications studies, Mosco (2004) applies the classical concept of the sublime to the then rapidly growing sphere of the digital and the Internet. In particular, Mosco (2004, p. 14) describes how cyberspace was a powerful myth that structured human thinking with regard to issues like the spread of democracy, economic growth or scientific progress. In essence, this was a continuation of previous enchantments provoked by railroads, television or, as in the present case, certain agrarian technologies. Hutchins (2015) deployed the metaphor of the 'digital sublime' to explain how the growing amazement at the amount of available sports statistics was actually obscuring the rising divide between data-rich, male-dominated disciplines; and data-poor, mostly female sports (Hutchins, 2016). As Lawhon and Murhphy (2012) explained on their proposal to study 'socio-technical regimes' and transitions to sustainability, narratives are fundamental to promote or suppress innovation. This review paper argues that the fetishization of technology described by Harvey, and the generalised awe defined by Mosco as 'digital' (or 'technological') sublime, are responsible for the lack of concern with the climate change question in recent summaries on the theme of digital agriculture.

It should be noted that most authors of the reviews collected on this paper are not blinded by technology; they are aware of the political economy, social differences and other factors that are currently and will in the future influence agriculture. However, the key argument here is that the influence of the 'digital sublime' operates to obfuscate what should be a clear issue with contemporary agriculture: the high environmental impact of digital farming infrastructures if they are installed following the current 'socio-technical regime', responsible for environmental degradation. In fact, the terrain where this 'digital sublime' is most successful is in structuring the vision of key international organisations and foundations in the sphere of global agriculture. A fundamental problem is the uncertain relationship between digitalisation and sustainability which, according to Gensch et al., (2017), is not really critically examined in European policy circles. Gensch et al., (2017) argue that technocratic thinking is either assuming a positive relationship between both processes, or simply ignoring the issue, when conceiving of digitally-enabled business models (Gensch et al., 2917, pp. 128-129). Certainly, since visions of a sustainable future are in themselves political, as described by Gillard et al. (2016), future researchers should analyse why certain assumptions could be problematic, and why alternatives are ignored.

The dangers of assuming an automatic relationship between sustainability and digitalisation were in fact noticed at the very birth of contemporary ITC technologies. About two decades ago, the following researchers warned of the dangers of mystifying these innovations' ability to overcome environmental limits. Matthews et al. (2002), supported by their studies on public and private sustainability initiatives, concluded that the spread of IT solutions in themselves did not contribute to improved environmental impacts. Governments and firms had to purposefully design sustainability plans (Matthews et al., 2002). Besides increased energy consumption in production and use of devices, an early analysis by Kuehr et al. (2002) also noticed the short lifespan of hardware devices: rapid innovation made them obsolete in increasingly shorter periods of time, around four years for an average computer. Other noticeable direct effects were mentioned by Matthews (2001) around the same period, as the development of e-commerce contributed to increased greenhouse gas emissions from air freights. From a behavioural point of view, Berkhout and Hertin (2001) warned about the problems of mismatch between micro-economic decisions that were believed to be sustainable but that contribute to unsustainable practices in the long run; something relevant to agrarian technologies. In fact, according to Fichter (2003), in addition to these direct effects, one should consider the indirect consequences of informatisation: for every digitally-enabled firm saving on polluting journeys to meetings; additional infrastructure was needed. This infrastructure, Fichter (2003) argued, depended on material flows that polluted the environment, from production to disposal of old hardware. Fichter (2003) called this a 'rebound effect': the net contribution of digital solutions to greenhouse gas emissions and other issues, explained by the fact that any reduction was smaller than the larger expansion of unsustainable practices like those described above. This can be understood through a simple example. A new generation of on-farm irrigation equipment might be less energy consuming; however, producing, taking to market, and end-of-life disposal of these new devices could ultimately be more polluting than simply upgrading existing infrastructures, instead of replacing them prematurely. As an alternative, Berkhout and Hertin (2004) suggested caution with regard to ITC's impact on the environment. Echoing Harvey above, rather than attributing revolutionary qualities to these technologies, it was more suitable to think about how systemic implementation of informatisation across the economy was favouring or disfavouring already existing tendencies (Berkhout and Hertin, 2004).

After these early warnings, it could be argued that two decades later, these impacts have probably accelerated. As described by Berthon and Donnellan (2014), computerised offices today use more paper than in 2003; and one-tablet-per-child style policies require a lot of hardware production but educational outcomes have not necessarily improved. Bates et al. (2015) take this analysis to micro-levels to conclude that even minor changes to domestic routines in cooking or entertainment can lead to the unsustainable multiplication of marginally useful smart devices. Greenpeace (2014) has noted how lifespans for ICT devices have decreased from four to one year. The organisation's examination of production the sector celebrates the generalised retreat from using hazardous substances; however, waste is still a problem and the creation of new products is very polluting: mobile production amounts to 60% of the devices' carbon footprint (Greenpeace, 2014:7). Also relevant is the growing role of rare earth mineral extraction. These raw materials are necessary for the production of most digital devices. According to Klinger (2018), our ITC-enabled economies' growing dependence on these minerals could be contributing to both environmental and social unsustainability in the fight for controlling extraction sites across the world. Equally, also according to Greenpeace (2017), the expansion in the use of electronics across the world has resulted in the IT sector being responsible for almost a tenth of total global greenhouse gas emissions. The growing necessity for computing power and data centres is resulting in higher power consumption (Greenpeace, 2017:14). Finally, as described by Chen (2016), the disposal of electronic waste in developing countries tends to operate through informal economic networks that have negative consequences for workers and the surrounding natural environment.

In sum, throughout their lifecycle, current ICT technologies pose great harm to sustainability. At the same time, like LeBel (2012) has argued, a conception of the 'technological sublime' (analogous to the 'digital sublime' described above) allows 'smart' solutions to appear detached from these resource-intensive processes of production, distribution and consumption. However, these devices are still the product of industrial practices and overall policies that contribute to environmental degradation. Accordingly, ignoring the contradictory narrative of digital artifacts, LeBel argues (2012), allows societies to dream with an ecological future powered by these innovative technologies. Kuntsman and Rattle (2019) have also called it 'digital solutionism', a mentality that delays taking action against the growing unsustainability of our digital present. Precisely because of this high material impact, the following discussion will highlight the importance of precaution in deploying digital agriculture.

6. Continuity, or socio-technical transition through digital agriculture?

There is no shortage of contributions that on-farm digital technologies can make to limit environmental impacts. Salam (2020) has recently described, among others, a wide variety of Internet of Things (IoT) applications to increase agrarian innovation. These are computing devices embedded in farming equipment or in locations across the farm, which are connected to software platforms. They can take the shape of, for instance, decision applications, wireless underground systems, soil and aerial sensing, water monitoring and sensors to support forestry activities (Salam, 2020:71-176). As referenced above, all of these will require infrastructures that rely on polluting production methods and consume energy, much like any other technologies. But precisely because of this tendency to globally increase impacts throughout their lifecycle, the human perspectives guiding these technologies should matter a great deal.

The current technological regime was defined by the previous 'socio-technical' transition, the 'Green Revolution'. Five decades into its deployment, Pingali (2012) assessed its results. On the one hand, the implementation of improved seeds, chemical inputs and innovative practices allowed greater access to food thanks to increased production. On the other, Pingali (2012:12304) explains, poverty and food insecurity persisted, particularly across gender lines. However, Pingali stresses, it was not the technologies themselves that caused these issues, but the policy frameworks employed in deploying them: agrarian agencies recommended, for instance, the application of artificial inputs in fields located in slopes; government incentives were mostly focused on productivity (Pingali, 2012). Eddens (2017) has also discussed how the model of research established by foundations like Rockefeller and developed country policy networks was based on a racial hierarchy. This hierarchy, Eddens (2017) argues, resulted in the appropriation of indigenous knowledge and its commercialisation for profit by transnational firms. While Pingali suggests these mistakes will not be repeated, other work suggests these issues of exclusion are not a thing of the past. Current 'Green Revolution' efforts in Rwanda, as studied by Dawson et al. (2016), are marked by a lack of consideration for local needs and experiences. Without impact assessments, Dawson et al. (2016) argue that smallholder farmers under existing agrarian perspectives are at risk of having innovation imposed, rather than being convinced of its benefits (Dawson et al., 2016). According to Gengenbach et al.

(2017), there is still a gender gap in the understandings of agricultural technology espoused by multi-stakeholder alliances like the 'New Green Revolution for Africa' (Gengenbach et al., 2017). Finally, Schurman's (2018) study of the Bill and Melinda Gates Foundation's work with smallholders in Africa reveals a lack of participatory involvement of stakeholders. While staff are concerned with improving livelihoods, their private sector backgrounds and other factors lead them to understand agrarian problems through the prism of commercial farming, which is not necessarily the most sustainable (Schurman, 2018, pp. 190-191).

These and other challenging accounts should not imply that the digital transformation of agrarian systems must repeat the mistakes of unsustainability and exclusion. Nonetheless, it is interesting to compare these arguments for caution with more enthusiastic pieces in favour of 'Green Revolution 2.0'. Llewellyn (2018, p. 218) argues that the next 'Green Revolution' will be even better than the previous one. Enabled by automation and low-cost digital devices, positive outcomes will depend more on technology and less on human inputs and changing approaches to farm management. In short, he argues, innovation can be trusted to increase farm efficiencies (Llewellyn, 2018). However, as Harwood (2018) shows in his classification of histories of the 'Green Revolution', it is hard to be so universally optimistic about the next systemic transformation, when there is actually no consensus on the previous one. Harwood describes how the wide variety of lessons and narratives that scholars have built on this period of agrarian history is sufficient to justify multiple and sometimes contradictory conclusions. Therefore, Harwood (2018) concludes, while this uncertainty should not justify technophobia in agriculture; it should make policy communities think twice before embarking on any wide-ranging 'socio-technical regime' transition. Harwood (2018:8) recommends that policies should be widely debated, launched and monitored at small scales before informing wider transformations.

It could be argued, surely, that certain researchers like Llewellyn are blinded by the 'technological sublime' and the expanded role of technology. But what will be the future of a farmer in an automated farm? The example of farming robots provided by Shamshiri et al. (2018) actually shows that human inputs, and human concerns (productivity, sustainability) will still matter. Certainly, on-farm digital solutions will depend on what Llewellyn and others define as 'smart systems': those which deliver solutions even before the problem can be detected by the human. In the case of crop plant sensor systems, Shamshir et al. (2018:11) discuss how human interaction will still be required in defining the proper course of action. A sensor might detect that a crop is not healthy, due to its colour, size or other attributes; however, it will find it difficult to ascertain whether this is due to lack of access to water or a particular pest. A human will need to make a decision according to its preference for productivity, sustainability or other values. Kesavan and Swaminathan (2018) make a different warning against the 'technological sublime' with regard to the applications of biotechnology in India, intended to address the costs of the first 'Green Revolution'. In fact, Kesavan and Swaminthan (2018, p. 1882) claim, the goal to reduce the use of pesticides was not accomplished, and the deployment of genetically modified crops had unintended consequences. In a similar vein, in their message to the European policy community, scientists Scholz et al. (2019) advice designers and policymakers should be wary of pushing for a systemic digitalisation of agriculture as a silver bullet. Obviously, the mixed legacy of past technological revolutions should not be an excuse to stop innovation altogether. Rather, policy entrepreneurs and other actors should adopt a precautionary approach to these technologies. Particularly, because some of them, like the World Bank or the Rockefeller Foundation, were attached to the previous 'Green Revolution'.

Indeed, the longstanding issue of inclusion is already a problem. Digital farming tools designed by larger agribusiness firms are mostly proprietary IT systems. For instance, in the case of smart tractors, farmers are prevented from accessing the engine control unit (ECU), which stores the information collected by their vehicles on their farms, as reported by Wiens (2015). Legal or simply technical obstacles prevent farmers from accessing information stored by John Deere tractors and drones. The company is busy in the agrarian start-up scene, acquiring firms which develop drones that would be able to pollinate and complete multiple tasks on behalf of farmers, as described by Kolodny (2017) and Ehrenberg (2018). As described by McDonnell (2014), through the combination of smart machinery and proprietary software, other firms like Monsanto are seeking to advice large farmers through decision, diagnostic and productivity tools. These farmers sign agreements which prevent them from accessing or modifying information outside the firm's established applications (McDonnell, 2014). The global reach of the company is intended to help collect as much information as possible throughout its business units in pesticides, fertilisers and seeds; later, as noted by Abram (2020), this data is re-employed to develop new products and approaches. This builds over their existing market dominance in conventional agriculture: for instance, the firm claims that their Seed Advisor digital tool recommends purchases based on the data library collected from farmers worldwide (Climate, 2019).

From the field of political economy, Srnicek (2016) explains private firm preferences for closed environments through network effects. Through network effects, they gather more data the more users they attract; and this data, in turn, makes them more effective and therefore more popular. As a result, Mooney and ETC (2018) have advised against the risks of promoting closed platforms and other proprietary software solutions in agriculture. They could actually fuel vertical concentration, as companies will attempt to gain control of vital bottlenecks. In the European Union, as Verdonk (2019) describes, there are particular worries about the corporate merger of Bayer and Monsanto's digital information. Mooney and ETC (2018) provide other examples through which industrial agriculture firms, those prospering in the current 'socio-technical regime', could gain control of key sector information and apply it to pursue profitable goals; but not necessarily those which are most sustainable (Mooney and ETC, 2018). As described by the report of the International Panel of Experts on Sustainable Food Systems (iPES, 2016), this economic concentration and reduction of diversity in approaches to agriculture could result in locking-in of unsustainability. In other words, in the maintenance of the existing 'socio-technical regime' in spite of technological innovation; because innovation effects are dependent on the *mentalités* or narratives attached to them.

There are, of course, alternative narratives that can guide digital agriculture, and can still be global in ambition and systemic in scale. While issues like cyber-security will indeed by important for certain types of farmers and firms, as discussed by Bogaardt et al. (2016); other farmers in the developing world (but also in developed nations) will be more concerned with the open dissemination of good practices through digital means. The World Bank *Digital Dividends* (2016) report shows that more than half of the bottom fifth of the poorest have mobile phone access today. As connectivity increases, developing country data becomes more valuable. Hartmann et al. (2020) have shown that, in Kenya, smartphone connectivity allows farmers to leverage expanded opportunities for export production (Hartmann et al., 2020). Next generation smartphone-enabled projects have also focused on services like digital marketplaces, insurance services, and advice about input use and intensification (cf. Carter et al., 2018; Chakravaty et al., 2018; Gashaw and Kibret, 2018). Other projects are also promising. ATA (2019) shows how mapping of soil fertility by Ethiopian authorities has increased productivity. In Nigeria, Oyinbo (2018) has studied, extension services provided through these and other type of digital applications resulted in improved crops for those farmers receiving targeted information. There is a risk, however, that foreign dependence on these technologies will limit access these technologies. As an alternative, Mann (2017) suggests, developing countries could aim to generate domestic digital industries based on this information; rather than allowing foreign investors to solidify the international division of labour (Mann, 2017).

In fact, there is already a solid foundation to build alternative digital platforms for farmers worldwide. In opposition to the proprietary systems of private actors, Wolfert et al. (2017, p. 76) explain how public institutions like universities and research centres are developing open public data farming applications, to facilitate precision agriculture and therefore achieve more sustainable operations. At the same time, Wolfert et al. (2017) observe a tendency for private firms to gradually enable data transfer and interoperability across platforms, through generic enablers like FIWARE. FIWARE, analysed by Rodriguez et al. (2018), is an open source platform supported by the European Union and managed by the FIWARE Foundation, where IoT (Internet of Things) applications can be designed. Through their Agricolus product, the authors explain, farmers can set up smart farming applications based on a "plug and play" principle to connect hardware with software (Rodríguez et al., 2018). Ash (2018) has also summarised other examples. For instance, *Farm Hack* (mentioned by Carolan, 2017) is a community of farmers who defend the right of farmers to access and modify smart tools. *Atelier Paysan* in France, according to Ash (2018), follows similar principles, but it is also a cooperative which owns tools and educates farmers. There are also other initiatives, like *The Open Source Seed Initiative* in the US, to facilitate the shareable codification of plant genetic information (Ash, 2018).

All of these initiatives are important for sustainability in themselves, since they encourage the right to repair devices, thus lengthening their life cycle; and can be helpful in spreading sustainability principles without having to sign up to proprietary systems. At the same time, they must be adapted to meet the diverse needs of farmers. In the field of agrarian modelling, important for extension services and other fields, Janssen et al. (2017) have argued that no single digital application will suit every beneficiary. These researchers also conclude that interoperability will be fundamental to make sure that tools fulfil their sustainability goals (Janssen et al., 2017, p. 210). On the global level, Antle et al. (2017) cite the Global Open Data for Agriculture and Nutrition (GODAN) as an example of the kind of transnational cooperation necessary to ensure that agrarian data harnessing, management and transfer practices are coordinated across borders (Antle, 2017, p. 182). In Kenya, Uganda, and other places, studies by Ogutu et al. (2014), Suri and Jack (2016) and Sekabira and Qaim (2017), show that government and civil society organisations can create applications that promote farm good practices in sustainability.

Equally, World Bank researchers Deichmann et al. (2016) have also admitted that, despite the potentials for digital agriculture to foster inclusion, efficiency and innovation; many of these experiences are hard to scale up because they cannot solve all the obstacles faced by smallholders. Digital policymakers and entrepreneurs should consider stakeholder needs. In fact, this is a necessary step to promote sustainable practices which already exist. For example, a qualitative study of short food supply chain farming in Greece by Lioutas and Charatsari (2020) highlights the benefits of opening up digital agriculture solutions to alternative farming approaches. In this case, researchers observed the mistrust of family farming consumers have towards smart technologies. Equally, these family farmers found no use to many technologies described to them by Lioutas and Charatsari; they were not adapted to their needs. Narratives matter, and both consumers and farmers felt excluded from the digital agriculture story. However, if public and private actors could direct their interest to tools servicing these and other constituencies, both authors argue they could provide a start for a sustainable transformation of agriculture (Lioutas and Charatsari, 2020).

Indeed, the preferences of farmers seem to coincide with the inclusive nature of open source software solutions. Schlaile et al. (2017), through on the ground surveys, have established how farmers would really appreciate a diverse variety of approaches, knowledges and tools being offered on their smart devices. At the same time, Lindblom et al.'s (2017) research alongside Swedish farmers and other stakeholders shows that, in the transition towards smart agricultural decision support systems, it is not enough to trust that technological deployment and minor adjustments will be sufficient to achieve sustainable goals. Rather, Lindblom et al. (2017, p. 327) stress that stakeholders and institutions have to wholly change their perspectives on farming and the role of agriculture in society. According to these researchers, technology implementation must be truly concerned with environmental targets from its implementation to the training with future users. In other words, policies must achieve what we described in the introduction as transcending the narrative or discourse embedded in the current, unsustainable 'socio-technical regime' of industrial agriculture.

7. Conclusion: leaving behind the digital sublime and centring sustainability in digital agriculture

This paper has conducted a qualitative, narrative review across recent interventions in the sphere of digital agriculture, a topic of increased interest for international organisations, governments, farmers and other stakeholders worried about sustainable intensification. At the same time, it has found that sustainability is not really recognised as a fundamental concern in key literature. As an explanation, it has deployed the concept of 'digital sublime', which operates to hide the strain of ICT technologies on the environment. According to the 'socio-technical regime' framework, this narrative will need to be overcome in order to overcome the unsustainable technological legacy of the 'Green Revolution'. Without a systemic approach to 'sustainable socio-technical transitions', the literature on digital agriculture risks ignoring the mentalities and practices that could entrench unsustainability.

As an alternative, apps and platforms should be designed from the bottom-up, listening to smallholders who are already conducting good practices and allowing them to spread through open systems. According to Fraser and Campbell (2019), this model could be called 'Agriculture 5.0', as it overcomes the shortcomings of both twentieth and twenty-first-century agriculture. As described by Bronson (2019) platforms like Farm Hack and open-source FarmOS encourage users to share their perspectives and learn together, without aiming to make a profit or nudge users towards certain solutions. Open blockchains, as defined by Lemeilleur et al. (2019), could also help facilitate the extension of environmental certification by generating automatic, transparent contracts for participating smallholders or cooperatives (Lemeilleur et al., 2019). Perhaps these examples can be replicated to pursue sustainable practices that achieve food security while respecting farmer autonomy across the world. Schueller (2016, p. viii) argues that maximum production and sustainability can be reconciled through technologies like automated pest control and monitoring of soil fertility. However, Schueller also concludes that no single technology will provide a silver bullet, particularly if their deployment is disembedded from social, environmental and other goals. To this reflection, we could add that no single understanding of digital agriculture should provide the silver bullet to meet human needs without compromising the future of the planet.

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