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Digital Technology and Power in Agriculture.

Technology Development, Data Valorization, and Sustainability Narratives in Germany

Introduction

In recent decades, digital capitalism has made its way into all spheres of social and economic life, including agriculture. Production processes, extraction of value and financialization have all become increasingly data-based processes (Haug 2001; Staab 2019). In digital agriculture, alongside the use of automated and GPS-enabled machines, farm data is increasingly collected by robots, sensors and drones, as well as by processing satellite imagery, and stored on digital platforms and in clouds. This provides inputs for "smart or precision farming" in the course of further advancing automation, digitalization, and the use of artificial intelligence in agriculture (Wolfert et al. 2017; Prause, Hackfort, and Lindgren 2020). The digital transformation in agriculture is widely presented by industry, politicians, and international organizations as a silver bullet for meeting multiple global challenges, such as achieving food security and adapting to climate change. It is seen as a pathway to sustainable agriculture and a win-win strategy that will benefit the environment, farmers, and consumers alike. However, recent studies of digital capitalism show how the digital economy is characterized by monopoly structures and concentration of corporate power, which determine patterns of control over digital technology, distribution of benefits, and value generation from data (Staab 2019; Srnicek 2017).

To investigate the political economy of digital agriculture this article puts corporate power relations center stage and examines how corporate actors exert their power to shape, and benefit from digital agriculture in Germany, while disempowering other actors and approaches. Empirical analyses of actors, interests and power relations are still rare in food and agricultural system research (Jacobi, Villavicencio Valdez, and Benabderrazik 2021). However, such analyses are highly relevant to assess the extent to which the technological transformation of agriculture is in line with sustainability goals.

Critical agrarian studies address political and economic asymmetries in agriculture (Akram-Lodhi et al. 2021). Food regime theory as a key conceptual contribution in this field pays special attention to power effects and class inequalities arising from the "corporate–environmental food regime" (Friedman 2005). Studies in this field also examine the power effects of technological innovation (Jayasuriya and Shand 1986; Patel 2013; WIELD, Chavez-Miguel, and BOLO 2010). Others analyze the emergence of inequalities among countries and farmers as a consequence of the adoption of agricultural biotechnology during the green revolution, considered as the dawn of the neoliberal restructuring of agriculture (Pechlaner and Otero 2008), and how it led to a dramatic increase in corporate power over food production (Clapp and Fuchs 2009). However, discussion of the political dimensions and implications of digital technologies in these debates is rather limited.

Recent studies in the field of agricultural innovation and technology studies focus on the role of digital technologies in agriculture and critically discuss the trends and effects of the adoption. These studies consider both the potential of digital agriculture and the challenges and risks it entails, including the social exclusion of farmers who have no access to the new technology (e.g., (Klerkx and Rose 2020; Regan 2019; Zscheischler et al. 2022). Yet, only few political economy-oriented studies in this field analyze how digitalization is transforming the agri-food system and highlight distributive issues and conflicts over data security and ownership, as well as the negative effects of concentrated corporate power. These studies reveal the multiple dimensions of inequalities and asymmetries among actors in digital agriculture, resulting in uneven technological development and unequal access to digitalization, as well as to the skills and resources required to benefit from it. They criticize the dominance of productivist approaches to food security that often come along with the technologies?, the focus on capital intensive technology development, and the marginalization of food sovereignty and low-tech approaches in respective associated debates and policies (Rotz et al. 2019a; Bronson and Knezevic 2019, 2016; Prause, Hackfort, and Lindgren 2020; Hackfort 2021).

However, the empirical dimensions of material manifestations of the digital transformation of agriculture and associated forms of power remain poorly understood. Most studies of underlying political issues are based on literature reviews and document analyses, or focus on conceptual aspects, with empirical studies being rather rare (Carolan 2020; Fraser 2021; Bronson 2019). Furthermore, most published research is on North America, with little information available on European countries (Hackfort 2021).

To fill this gap, this article presents the results of an empirical investigation of the power relations in digital agriculture in Germany to answer the research question: *How do corporate actors and existing power relations shape the development and distribution of benefits of digital agriculture in Germany?*

Germany was chosen as a case study due to its relatively high level of technological development in the agri-food sector and because it has adopted far-reaching (agricultural) policy goals relating to social and ecological sustainability (MacPherson et al. 2022). Digital technologies are quite advanced in German agriculture and constitute one strategy of the German government to make agriculture more socially and ecologically sustainable and resilient. The use of automation and digital technologies is intended to reduce the negative impact of industrial agriculture on the environment and climate, while at the same time increasing the productivity of farms and making work on farms easier and more attractive (BMEL 2021). Nonetheless, there is almost no empirical work that goes beyond analysis of potential current and (future) risks (Zscheischler et al. 2022), pointing to a clear research gap.

While there is no comprehensive statistical data on the use of digital technologies in German agriculture, several studies analyze their adoption and acceptance (Gabriel and Gandorfer 2022; Spykman et al. 2021; Michels and Mußhoff 2022). A survey of 500 farms conducted by the digital industry alliance Bitkom and the German Farmers' Association suggested that about 79% of farms use some form of digital technology. GPS-enabled tractors for large field farming are used by more than the half of German farms (59%), while 39% use apps for real-time documentation and analysis of fields. One third of farms (32%) use farm or herd management software. Less widely adopted are more complex digital technologies such as drones (19%), artificial intelligence (14%) or field robots (4%) (Rohleder 2022). According to another recent study, which surveyed about 400 farmers and other stakeholders (NITT 2022), the main barriers to larger scale adoption of digital technologies by farmers include the high investment costs, low expectations of economic returns, and concerns about data protection and security. The limited data that exists shows that digital agriculture has taken root in Germany; however, its adoption is unevenly spread, while further development hinges on diverse factors, including economic ones. While these finding are important, empirical studies of the underlying political economy of digital agriculture in Germany, including a critical examination of the actors and how power relations among them shape the distribution of benefits, are still lacking. This article contributes to filling this gap. It presents the results of a qualitative study based on empirical data derived from expert interviews and stakeholder workshops in Germany. It provides valuable empirical insights that complement existing critical analyses of digital technological transformations in agri-food systems. By using Germany as a case study, it contributes to the development of critical agrarian studies in the global North, a field largely dominated by perspectives on the Global South.

The remainder of this article is structured as follows. The following section illustrates the value of political economy as a conceptual approach. The next briefly elaborates on the data and methods that are used to answer the research question. This is followed by the presentation of results, focusing on the different ways in which material and discursive forms of power play out in the political economy of digital agriculture in Germany. The article concludes with some final remarks on power and technology.

Analyzing Power through a Political Economy Lens

This article draws on political economy as a conceptual lens to facilitate examination and understanding of past and ongoing transformations of agri-food systems, with regard to power relations, the roles of actors in shaping technologies, their interests, and the distribution of benefits. The political scientist Colin Hay describes power as being "*. . . about context-shaping, about the capacity of actors to redefine the parameters of what is socially, politically and economically possible for others. More formally we can define power . . . as the ability of actors (whether individual or collective) to 'have an effect' upon the context which defines the range of possibilities of others.*" (Hay 2002) 74). Key questions regarding power relations in food and agricultural systems include: "Who owns what? Who does what? Who gets what? What do they do with it?" (Bernstein 2019): 22-24).

Corporate power relations are a key issue and the subject of much political economy research on agri-food systems (Bastos Lima 2021; Ashwood et al. 2022; Clapp 2021).This article builds on this rich body of work to operationalize the analysis of power relations in digital agriculture. This focus is legitimate and necessary because corporate actors have a strong influence on how we produce food, and what technologies get developed. Moreover, they actively attempt to influence policies that shape agricultural systems and decisions about what counts as sustainable. Different forms of power are employed to shape the decision making context and the conduct of others: In their classic volume corporate power and global food governance, Clapp and Fuchs distinguish between *instrumental, structural, and discursive* power (Clapp and Fuchs 2009). *Instrumental power,* also called the 'first face of power' (Lukes 2005), is exerted through "direct influence of one actor over another" (Clapp and Fuchs 2009): 8); that is, by imposing one's own will over others. This may be achieved through political lobbying, or by using financial, organizational, or human resources to shape technological innovation. *Structural power*, 'the second face of power' (ebd.), exerts a more hidden influence on agenda setting by influencing regulatory institutions and processes, in ways that favor one's own interests and constrain the options of other actors. *Discursive power*, the 'third face of power' (ebd.), uses a variety of ideological strategies to shape public discourse, to confer legitimacy on contested problem definitions and obtain public support for preferred solutions. This could include influencing debates on what is understood as sustainable or efficient, or on what needs to be regulated (or not), and how (Clapp and Fuchs 2009). This link between discursive power and regulation makes it clear that these different forms of power are not completely separate from each other; they are intertwined and likely to be mutually reinforcing. This entanglement allows for alternative classification systems. In their work on corporate power in 'climate smart agriculture' (Newell and Taylor 2018) Newell and Taylor distinguish between *material, institutional and discursive* forms of power and argue that these are key for understanding conflict, contestation and consensus from a political economy perspective (Newell and Taylor 2018, 3). The analysis of institutional and discursive power is important to show how policies and practices are framed and implemented in particular ways and become embedded in institutions. Material power is key for understanding how the power of dominant agribusiness actors derives "from their control over production, finance and technology in the current food regime" (Newell and Taylor 2018): 119).

Despite their use of different terminology and small differences in the way they conceptualize different form of power, both of the above approaches to corporate power in the agri-food sector highlight the importance of material power—in its structural and instrumental forms—and discursive power alike. The following section describes how this power lens was employed to examine power relations in the development of digital technologies and the distribution of the benefits of digital agriculture in Germany.

Methodology

Qualitative empirical data was collected in a case study of Germany carried out in 2020–2022. Interviews were conducted online or by phone with 30 experts selected based on desk research and snowball sampling. The interviews were semi-structured, following interview guides specifically designed for each group but all broadly covering the following topics: a) motivation and interests for technology use or development, b) target groups, main clients of business model, c) technological impacts on production processes and labor, d) available funding and investment for technology development or purchase, e) type of data collected and used or feed into systems, and its relevance for business model, f) company's data policy or position on data sovereignty issues, g) political regulation demands or policy recommendations, g) and future visions of agriculture.

The interviews were supplemented by participant observation in 9 online stakeholder workshops, each with about 15–16 participants, with a total of approximately 140 participants. The workshops each covered one topic of the following: 1) potential farm benefits, 2) economic costs and profitability, 3) ecological effects, 4) data use, 5) security and compatibility, 6) production systems and business models, 7) impacts on labor, and 8) political context conditions.

Field notes and records of observations were compiled during and after each event. The stakeholders who took part in the study represented all key interest groups in German agriculture, and included representatives of the agricultural machinery industry, agrochemical and seed industry, agricultural platform services and software providers, agricultural advisors, ministries and federal agencies, chambers of agriculture, academics from universities and research institutions, farmers associations, and organic and conventional farmers.

The empirical material was recorded and subsequently transcribed or, in some cases where recording was not possible, detailed field notes were taken. The software program MAXQDA was used to organize and code the material in the subsequent qualitative data analysis (Kuckartz and Rädiker 2020). Briefly, the material was subject to in-depth qualitative analysis using deductive coding to examine a) definitions of technology, high technology or digitalization; b) technology-related problems, and challenges; c) actors and their interests and strategies in relation to technology development; (d) distributive effects related to technology development or data use; (e) discursive framings, narratives, and concepts of legitimacy (e.g., sustainability); and f) manifestations of different forms of power.

Additionally, this study draws on 'digital ethnography' methods and includes findings from using farm management software and analyzing license agreements. The empirical material for this study was further complemented by extensive reviewing of industry reports and academic literature on digital agriculture over the past two years (of which the results have been previously published as Prause et al. 2021 and Hackfort 2021).

Material and Discursive Power in Digital Agriculture in Germany

Technology development for large-scale and capital-intensive farming

The results confirm that corporate agribusiness and agricultural technology companies broadly shape the development of digital technology products and services for agriculture in Germany. Apart from a few start-ups that have gained a foothold in the market, provision of digital technology and services for German agriculture is dominated by large companies producing agricultural seeds, biotechnology, pesticides, and fertilizers (e.g., Bayer, BASF, and the Norwegian multinational Yara), and leading farm equipment manufacturers (e.g., John Deere and CLAAS) (BC, 75). These actors, who are already very powerful because of their high market shares (BC, 77), develop digital technology for agriculture predominantly for large-scale and capital-intensive agriculture. US companies such as John Deere slightly adapt their digital tools for use on smaller farm fields than in North America and to respond to other requirements of German farmers. However, they basically operate similar models to in North America, offering big land machines and platform solutions for large-scale grain, dairy and livestock farming or high value crop production. A German John Deere representative stated that the company's technology development for German markets is directed towards medium and large-scale arable farms that can afford to invest large amounts of money in technology (JD, 30). Smaller field robots are on the market, but their use is still very limited. They are mainly used for highly specialized operations, for example, by producers of organic crops (e.g., for weeding organic sugar beet) or labor-intensive high value crops (GR, 16). Generally, digitally enabled machines are getting bigger and more expensive, rendering digitalization unaffordable for many farmers (CL, 16; AK, 80-84).

Prices and maintenance costs of smart land machines are too high for many medium-sized farms in Germany, particularly in comparison with the cost of manual labor by seasonal workers, at least for staple crops (JG, 52).[1] Most farm management platforms, field robots and smart land machines are designed for conventional large-scale agriculture, with industrialized production of monocrops on square fields and a focus on higher yields; they are much less suitable for small-scale, agrobiodiverse or agroecological agriculture (DK, 18; FD, 44). Solutions for these sectors, such as specific seeding and weeding robots, are still niche products and small-scale adaptability is not currently among the goals of mainstream technology developers (GR, 16, KR). This bias was summarized by one stakeholder who took part in the study, who stated that technology development is driven by the tech industry, and not for sustainability but for productivity (DK, 81); from this perspective, nature needs to be adapted to fit the technology (FD 44).

Many of the companies with the instrumental power to develop digital machinery and applications for the German market, such as BAYER, John Deere, BASF or Yara, represent and benefit from the large-scale agro-industrial model. Not surprisingly they develop technologies that service and reproduce agricultural models based on a productivist strategy. If technology development continues in accordance with this model, advances in digitalization can be expected to further enhance the dominance of agro-industrial farming and, by extension, the disempowerment of alternative farming approaches.

Interoperability, incompatibility, and lock-ins

The results of the study show that market concentration in Germany is lower compared with North America, where just a few machinery companies dominate the markets for machinery and agtech software. Compared to the US, the German market and actor landscape are more heterogenous. However, this heterogeneity is a major reason for the lack of coherence, compatibility, and interoperability among digital systems, which is one of the main challenges encountered by German farmers (BC, 89). As a result, farmers tend to be on the receiving end in the market, struggling to cope with a lack of interoperability, a consequence of technical lock-ins built into their products by technology and service providers. Lock-in effects seriously constrain farmers' options to freely choose other software or hardware equipment according to their needs. The costs of switching to a different provider are high once money has been invested in expensive land machines. Technical and legal lock-ins are one of the strategies used by companies to maintain their market position and trap farmers in their economic-technological 'ecosystems' (BC, 69). This is an example of companies using their instrumental power to "define the range of possibilities of the farmers" (Hay 2002: 74). For example, a farmer using the N-Sensor developed by the fertilizer company Yara is unable to transfer the collected data to a different system without using the company's online platform (FG, 172-174). Similarly, the US company John Deere is well known in Germany for its use of locked

[1] By contrast, automation and digitalization can reduce production costs of labor-intensive high value horticultural crops, such as strawberry or asparagus where (Prause 2021).

proprietary technologies to draw all the farmer's activities into their technological ecosystem (BC, 69; FG, 51, 203; KR, 19). Alongside these technical lock-ins, there are 'soft' lock-in strategies which the companies use to create path dependencies for farmers, such as the free starter packages to attract clients marketed by John Deere (JD, 57; (FG, 203-204). Farmers become dependent on these systems after having invested in machines or software and used them for a while, since the transaction costs of change to another system are high. Some experts refer to John Deere as "the Apple of agriculture" to highlight that the proprietary strategies employed by agtech corporates is analogous to those used by producers of digital consumer products (GR; FG, 203-204; LA, 20). This leads to the perception among stakeholders that the digitalization of agriculture in Germany is currently not driven by the needs of farmers or motivated by a desire to benefit farmers or contribute to sustainability goals. Rather, it is driven by the tech industry and tailored to the needs of agribusiness, including input and machinery manufacturers, service and technology providers, and the food and biomass processing industry, and oriented towards their goals of high productivity and yields (DK, 81).

Interestingly, some actors in the machinery industry recognize that, in the long run, data incompatibility and the lack of systems interoperability risk undermining their own business models in an increasingly competitive environment (FG, 201). The ISOBUS standard provides a universal interface for machine communication, but it is 20 years old and rather out of date (KR, 11, 23; CL, 48; JD, 53). Hence, some firms are now developing more advanced non-discriminatory farm management systems that allow combination of several different machine brands, tools, and applications in one management platform (FN, 30, 42; FG, 201). One such example is 365Farmnet, a CLAAS supported start-up that provides a platform to host a whole ecosystem of applications combining different brands in accordance with the needs of the client (CL, 28). The German company Krone is also collaborating with partner firms to develop systems that enable the users to connect and operate different machines at the same time (KR, 19). Another recent example is DataConnect, a cloud-based interface supported by CLAAS, John Deere and 365.Farmnet that enables the exchange of data from different machines and allows clients to view all information from their mixed fleet on a single platform of their choice (JD, 57; DK, 17-19). However, DataConnect currently incorporates only a limited range of machine data, and no agronomic data at all (BC, 43; JD). Another recent innovation, *Agrirouter*, translates and connects data streams from different land machinery companies, including Amazone, Krone and New Holland but not John Deere and CLAAS. This virtual software tool enables exchange of encrypted information between, for example, the client's own farm management system, the ISOBUS-Terminal and a smartphone app for fertilizer application. To sum up, companies are adopting different strategies and approaches. Some adopt a more proprietary attitude towards the use of their technology, while others are willing to collaborate in opening up their systems to allow data to be transferred more easily (GF; FG, 203-204; BC, 43).However, despite these efforts, the lack of interoperability and compatibility of software and hardware systems of different manufacturers and providers is a persistent problem for farmers in Germany (ABL, 21; BC, 43). This demonstrates the instrumental power of corporate technology providers and machinery industry. Technology provider companies exert their power by using their own coding languages and developing incompatible tools, making farmers largely dependent on proprietary software and hardware systems. Farmers usually lack the capacities and resources to fix problems themselves. The systems are "black boxes" —as one farmer put it (JG, 36-38)—and farmers are highly dependent on the support of the companies' own IT experts and advisors.

Limited data sovereignty and value from data for farmers

Digital agriculture increasingly depends on the collection, extraction, and analysis of large amounts of agricultural data. This 'big ag data' is collected on, for example, soil and seed quality, fertilizer and pesticide application, crop yields, and animal health. Farm management platforms offered by many leading global suppliers of agricultural inputs and machinery have become an important tool for farmers, helping them to make data-driven decisions on the management of their farms. For example, crop data is transmitted directly from harvesting machines to the platform, which combines it with data on weather and possibly soil quality to generate recommendations for next year's sowing.

Companies such as John Deere or AGCO have direct access to the data that is collected via the sensors and GPS systems installed in their machines when they are sold (AK, 42; BC, 37).

Big ag data is often stored on servers belonging to large US companies. German or European companies often lack sufficient data storage capacity, and their servers are less reliable and efficient. Hence, many firms in Germany, including technology and service providers for farm management information systems such as 365Farm.net, use Amazon's AWS cloud computing service (BC, 51; FN, 22; KWS, 43). If farmers use such services and their data is stored on US servers, it is subject to US data regulation governance and may be made accessible to third parties in the US under the US Patriot Act (Datenschutzexperte.de 2022).

However, even if data is stored on German or European servers, the ownership of farm data and legal control of its use are poorly regulated, with few legally binding instruments in place. The European General Data Protection Regulation (GDPR) only covers personal data, not business data. Moreover, German civil law does not recognize data as 'property', or any related claims, due to its alleged 'immateriality'(Vogel 2020) (Härtel 2020). Thus, German farmers do not own their farm data or have any legally secured control over its use. This is recognized by experts as a regulation gap (DK, 45) that makes it possible for private companies, whether US based or European, to decide what to do with farmers non-personal data (FD 141).

In the absence of effective regulation, service and technology providers exert their structural power by setting up their own rules on data sovereignty and enforcing them through license and user agreements. The farmers usually accept them, rarely knowing what kind of regulatory standards apply or what their data may be used for (Ref.). Some companies base their license agreements on a European Code of Conduct drawn up by the industry and farmers alliances; others simply state that they treat farm data as personal data and thereby subject its use to the higher standards of GDPR regulation (BC, 64-65).

However, such voluntary commitments are insufficient to ensure that the interests of farmers are sufficiently considered. How farm data is used is not determined by legal standards but rather by each company's specific preferences and practices, leaving them at the mercy of their data monopolies.

This demonstrates the asymmetrical relations of structural power among the actors involved. Current law in Germany and Europe does not protect farm data from access or further use by service or platform providers or other third parties (Vogel 2020). In fact, current EU data law allows third-party access to data, thereby disempowering farmers from control over their farm data (Kosior 2019; Atik/Martens 2020). The current legal framework means that the amount of data generated on a farm is almost inversely proportional to the degree of control that the farmer has over it (Vogel 2020): 331).

Value from Data – "Data is essential for further development of products"

Technology and service providers benefit from data freely provided by farmers—on seed varieties, fertilizer quantities, planting dates, soil quality etc.—which has high use value as an input for the further development of data-based services. While the farmers still own the fields, they cede control over their data to the providers. Farmers then pay the same providers to access services generated in part from their own farm data, which they fed into the system and for which they received little or no remuneration. Private technology and service providers exert instrumental and structural power over hardware and software development, and over data collection and storage, to appropriate the value of the data. (Rotz et al. 2019b): 117) argue that this "unpaid work under digital capitalism" turns farmers into "digital laborers". As explained by the representative of a German machinery company who took part in the study: "*Data is essential for further development of products.*" (KR, 37; CL, 32). Hence it is not surprising that companies invent creative marketing strategies and business models to keep effective control over farm data and thereby maintain their structural power.

Participants in the study repeatedly mentioned John Deere as being well known for its closed technology ecosystems and use of lock-ins, and for being "smart" in making use of the benefits of digitalization (ref). For instance, by offering 'predictive maintenance' services to farmers, JD provides incentives for them to waive their rights of anonymity and allow tracking of data about their farms and land machines, in order to activate 'expert alerts' when problems are detected (JD, 26). The predictive maintenance contracts represent an additional cost for farmers, who pay JD to monitor of the condition of in-service equipment and decide when maintenance work is needed. But in fact, farmers can be said to pay twice, since they also pay 'in kind' by freely providing data that JD then uses to improve the performance of their products (e.g., by analyzing data on driver behavior, and engine load) (JD, 51).

Such deals are clearly of interest for the companies and help them to improve its products and contribute to the further development of data-based technology, thereby gaining a competitive advantage in the market. At the same time, they benefit from strengthening the relation between the company and its clients—or in other words: from farmers' dependence on the machinery and services they provide (Quote in Kundenbeziehung Krone oder bitcom).

If a farmer decides to opt out and withdraw consent in the further use of their data, they no longer receive advice from the company on machine maintenance or farm management (JD, 51). This is obviously disadvantageous to the farmer and can be understood as another 'soft lock-in' device that motivates the farmer to consent to data sharing, since the costs of not doing so are too high.

Service and technology providers use multiple lock-in mechanisms to access and maintain control over data because they are aware of the value of big ag data. They know that they have multiple opportunities to extract value from this data, which are unavailable to farmers who possess only their own data sets (BC, 55). Thus, there is an imbalance of structural power between those who control the big data and those who do not. Alistair Fraser has coined the term 'data grab' to describe the appropriation of farm data that perpetuates the structural power of big service and technology providers (Fraser 2019). The fact that companies are legally allowed to set the rules, and farmers can only accept or decline, highlights that the structural power of the former and the disempowerment of the latter is sustained by German and EU policy and digital law.

The 'digital fix' and its promise of precision for sustainability

Corporate agribusiness and the agtech industry not only drive the technical development of digital agriculture. They also use their discursive power to advance the narrative that digital technologies contribute to sustainability by improving farm productivity and efficiency. This 'sustainability narrative' has been picked up by institutions such as the Food and Agriculture Organization or the European Union, as illustrated by the recent announcement by the European Commission that "digital technologies (…) have the potential to increase farm efficiency while improving economic and environmental sustainability" (EC 2019). The EU also supports the sector through funding for research and development, with the aim of establishing "a Europe-wide innovation infrastructure for a smart European agri-food sector and a European dataspace for smart agri-food applications" (EC 2019). In Germany, digitalization is one of the main action areas in the Federal Ministry of Food and Agriculture's '2035 Arable Farming Strategy' (Bundesministerium für Ernährung und Landwirtschaft (BMEL) 2019). The former German Minister of Agriculture Julia Klöckner described "digital applications [...] as solution providers" for ecological, economic, and social sustainability in agriculture (Dahm 2021: n.p.), and as a key component of the country's agricultural modernization strategy. This echoes similar statements by agricultural corporations such as Bayer or John Deere; for example, Bayer promises that with its digital tools it is developing "new solutions that help farmers withstand the impacts and address the causes of climate change." (Bayer 2022).

"Precision is the key for a sustainable future"

One key narrative that is repeatedly put forward to support this claim is the degree of precision made possible by application of the new technological tools. According to John Deere "*precision is the key* *for a sustainable future (...)*". It is claimed that precision farming will make agriculture "more efficient and more sustainable"[2]; for example, by using variable rate technologies that allow fertilizers and pesticides to be applied more precisely, so that the absolute quantities of agrochemicals are reduced (JD, 28). On its website John Deere declares that savings of up to 90% in pesticide applications could be reached through the use of its artificial intelligence-based plant recognition technology.[3]

Interestingly, some participants in this study, in particular farmers but also academic scholars, were quite critical of these claims made by the industry. One point of concern articulated by farmers was that digital tools do not necessarily reduce the use of farm inputs but can in fact lead to increased use due to rebound effects, prompting farmers to apply even more fertilizer on the parts of the field with lower projected yields (FG, 31).

One example of such a variable rate technology is the use of near-infrared light (NIR) sensors, which are supposed to precisely measure the nutrient contents of fertilizer. JD claims that use of this technology will enable farmers to apply fertilizers much more efficiently and thereby contribute to reducing CO_2 emissions from fertilizer production (JD, 28). In fact, empirical evidence shows that savings do not reach significant levels, for example, not exceeding 10% for nitrogen using NIRS technology (WS IZT). A recent report commissioned by the German Environmental Protection Agency confirms just how small the contribution to sustainability and environmental benefits of digital farming currently are (IÖW, TAB, Bfn Studie).

Furthermore, the precision offered by the software and hardware tools themselves is limited and often less than what is promised in marketing materials. For example, one farmer reported that farm management planning tools malfunction in cloudy weather (FG, 153).

Another example are field robots, which are widely presented as innovative solutions for sustainable small-scale farming, as they not only replace scarce manual labor but can also eliminate the need for glyphosate and other herbicides through mechanical weeding. However, here also product development still lags behind expectations and the performance is less than advertised. Participants in this study described a range of problems, including unstable internet connections and poor signal reception; poorly manufactured hardware, leading to malfunctions; programming bugs in the apps and software; and slow data processing and updating (FD 65).

These findings from this empirical research in Germany resonate with recent literature that shows how imprecise these 'precision tools' sometimes are, and that the promised benefits for sustainability are mostly based on future expectations rather than empirical evidence. Studies show that corporate actors' claims that the use of precision technologies reduce agrochemical use are not evidence-based (Clapp and Ruder 2020): 56). As (Leroux 2021): no page) points out, "*proponents of precision in multiple policy domains claim that its value lies in its future value, as new associations are made visible through various automated analyses. This shift to the future is key to the speculative political economy of data, in which assumed future use and exchange value is presented as the justification for collecting data in the present (...).*"

The alleged precision of digital agriculture, and associated sustainability benefits, is one of the principal narratives used to legitimize funding support (Visser, Sippel, and Thiemann 2021; Clapp and Ruder 2020). However, one of the main funding schemes for farmers in Germany (the so called *Bauernmilliarde* or 'farmers' billions') provides support for farmers to invest in machinery based on lists of approved brand-specific machines and applications, rather than target-oriented funding. Critics argue that this kind of funding model reproduces path dependencies; moreover, a much more

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[2] https://www.deere.de/de/blog/articles/management/gruene-woche-1/ last accessed August 28, 2022)

[3] https://www.deere.de/de/blog/articles/management/gruene-woche-1/ (last accessed August 28, 2022)

efficient way to contribute to innovation and sustainability goals would be to provide targeted funding to evidence-based technologies, for example, those proven to reduce fertilizer use, rather than subsidizing a specific technology or brand (Köhler, DBV in Workshop).

To date, there is no reliable empirical evidence of significant sustainability gains from increased precision following to the adoption of digital technologies by German farmers. Advocates of digital technologies, however, frame this "inadequate or inaccurate functioning of the technologies, (…) as a transitory problem as the technologies will become constantly more powerful and accurate" (Leroux 2021): n. p.). (QUOTE von Ruckelshausen)

The materiality of technology

Another concern raised by some stakeholders from alternative food movements who took part in the study relates to the material inputs for digital infrastructure, and its resource use, including for data processing, an aspect that is hardly ever considered in corporate sustainability claims (ABL; SOL, 33). But digitalization is not immaterial; it is a highly material phenomenon and as such it merits further attention and analysis. As recent studies highlight, the resource demand of precision agriculture is very high, because of the large amount of energy required to operate the infrastructure, including servers and for data processing (Gugganig and Bronson 2022). The digital economy currently accounts for 4% of global CO_2 emissions and the sector is growing fast. With no monitoring or quantified assessment of the emissions of digital technology in agriculture available, it is impossible to claim that digital farming is effectively helping to reduce greenhouse gas emissions or to make even broader sustainability claims (Leroux 2020).

To sum up, the results of this study show that precision narratives and sustainability claims are created and maintained by discursive power. The fact that these narratives have taken root, despite a lack of empirical evidence, demonstrates the power of the actors who disseminate them. In Germany, as elsewhere in the world. the agricultural and tech companies are allied with powerful national and international policy actors. The results suggests that sustainability and environmental narratives are being used to legitimize a digital transition in the agricultural system whose contribution to a more sustainable agriculture is yet unproven. This acquired legitimacy might prevent critical questions from being raised about actual environmental effects, as well as related social and political issues such as data and food sovereignty, and corporate control over farming practices. The acceptance of narratives linking 'sustainability' to the application of digital technologies allows corporate actors gain institutional support for their technological developments and to consolidate and advance their structural and instrumental control over agricultural technologies and food production. At the same time, this use of their discursive and material power can explain the disempowerment of alternatives based on low-tech agriculture, agroecology, or organic agriculture and marginalization of the latter in international and national policy-making arenas. At both national and international policy levels, there is an 'overemphasis of high-tech solutions' in food systems (Klerkx and Rose 2020): 2), while there is little support for, or even mention of alternative narratives and practices inspired by visions of an agricultural future no longer dominated by industrial production (Lajoie-O'Malley et al. 2020). Moreover, the results show that solutions which are being developed for alternatives to corporate agriculture and explicitly targeting small-scale production, such as field robots, are struggling to overcome technical limitations also due to a lack of lobby support and funding.

The results highlight the entanglements among different forms of power and show how discursive power can also translate into institutional or structural power when narratives are advanced that shape policies for digitalization in accordance with the interests of powerful actors. The emphasis on high-tech 'digital fixes' makes it more difficult for other approaches and models of food production to gain a hearing, as pointed out by proponents of the food sovereignty concept. However, the focus on high-tech solutions suits powerful actors from agribusiness because they contribute to maintaining the status quo and to diverting attention away from the need to transform agriculture, challenge structural inequalities, and address ecological externalities.

Conclusion

Technology is never neutral, in fact it has highly political implications and is always related to questions of power (Winner xxx). The advent of the digital economy in agriculture—bringing together two fields dominated by powerful corporate actors and interests—makes it important to critically assess dimensions of power. This article presents and discusses the results of an empirical study in Germany and finds patterns of power and inequalities that are similar to those reported in the international literature. Of course, there are regional differences; for example, between what counts as large-scale in Germany or in North America, and in the degree of market concentration. However, corporate actors in both contexts make effective use of both material and discursive form of power. This is highlighted by the focus on 'digital fixes', and widespread acceptance of the narrative of precision-led sustainability, despite the lack of any empirical supporting evidence.

The dawn of digital data in agriculture has created a new resource for value extraction that reinforces preexisting power asymmetries between corporate actors and farmers. Digitalization reflects existing power relations and reproduces existing asymmetries. So far, hopes that digitalization might prove to be emancipatory, due to the nature of the technologies, have not been realized, due to the persistence of unequal social and power relations in which they are embedded. In Germany, based on current trends, digitalization seems likely to lead to profound changes in the way agriculture is practiced in rural areas, but not to structural agrarian change. This suggests that digital agriculture is less of a revolution than is sometimes suggested.

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