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# Perceived risks and vulnerabilities of employing digitalization and digital data in agriculture – Socially robust orientations from a transdisciplinary process

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ABSTRACT

The digitalization of agricultural production and the use of digital data are fundamentally transforming processes, products, and services of the agro-food systems. Digitalization improves efficiency and facilitates sophisticated farm management, thus increasing productivity, efficacy, and profitability. At the same time, it promises many opportunities for a more sustainable and, especially, more ecological and cleaner agricultural production. However, with it comes the potential for a number of unintended side effects and risks that may increase the vulnerability of agricultural production and have, thus far, received scant scientific and societal attention. This article presents the results of a two-year transdisciplinary process that aimed to identify unintended side-effects (short “unseens”) and perceived risks of digitalization in German agriculture. Results base on a triangulation of knowledge integration from the transdisciplinary group process involving twelve representatives from science and practice and an ethnographic qualitative meta-analysis. The findings have shown that, despite digitalization’s numerous promises for a more ecological and resource efficient agricultural production, a broad range of risks was perceived by some key stakeholders involved. These risks were anticipated to be caused by unintended negative and uncertain side effects on agro-ecological and social systems. Data rights, the restructuring of the value chain with new market concentrations, power structures and dependencies, changing knowledge requirements for farmers (lacking “digital literacy”), and information asymmetries that may cause potentially negative effects on food security were identified as causal factors. Based on these results, we co-developed socially robust orientations (SoROs) for coping with resulting risks and vulnerabilities. We argue that these SoROs provide perspectives on how anticipated knowledge can be turned into responsible action within the RRI (responsible research and innovation) framework. Finally, with regard to the preventive and anticipatory paradigm of “cleaner production”, our transdisciplinary methodology shows a way to adaptively govern the highly complex socio-technological transitions of digitalization in agriculture in the sense of a sustainability-oriented transformation.

## 1. Introduction

Digitalization and the use of digital data are fundamentally transforming agro-food systems, resulting in far-reaching changes along the agricultural production chain. This transformative process is currently facing a new evolutionary stage of digitalization and technological progress in which the further development of information technologies such as the Internet of Things (IoT), cloud computing, big data analytics, and artificial intelligence (AI) are greatly accelerating the digitalization process (Aravind et al., 2017; Qi et al., 2021; Verdouw et al., 2021; Zhai et al., 2020). Digital data become a new type of monetary operating resource that, together with algorithms, permeates all domains of

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human activity (Wolfert et al., 2017). The digital linking of almost all processes along the agricultural production and value chain (IoT) is seen as "game-changing" (Klerkx and Rose, 2020) and constituting a next "technical revolution" in agriculture (Walter et al., 2017).

This next stage of digitalization in agriculture leads to not only a number of new opportunities but also consequences. The socio-technical transitions of digital agriculture and smart farming imply many promising benefits and potentials (Eastwood et al., 2019; Rijswijk et al., 2021). Digitalization advances in the agricultural production chain offer economic potential due to improved efficiency, better-informed decision-making, increased productivity, and greater profitability (Bronson and Knezevic, 2016; Jakku et al., 2019). Furthermore, such transitions are promoted and expected to improve resource and climate efficiency, biodiversity and animal welfare, and to increase the transparency and traceability of food production for consumers. In this way, digitalization can also help to improve trust in and acceptance of agricultural production methods (Walter et al., 2017) that have been tarnished among some segments of the public (Pfeiffer et al., 2021). Worth highlighting are related opportunities for more sustainable and environmentally friendly agricultural practices stemming from more precise applications of nutrients and/or pesticides that are adapted to the conditions of the plant, soil, and other environmental factors, as well as reductions in effluents (Balafoutis et al., 2017; Finger et al., 2019; Walter et al., 2017) and GHG emissions (Balafoutis et al., 2017). Furthermore, improved monitoring possibilities and a higher quality of information that can be provided by digital technologies result in new options for the design and implementation of agricultural policies (Ehlers et al., 2021). Altogether, these opportunities can help mitigate global food challenges posed by climate change, soil degradation, and the world's growing population (Carolan, 2017; Regan, 2019).

However, the digital transformation is strongly driven by new technologies and algorithms that are not neutral and provide no guarantees that these positive effects will result (Fleming et al., 2021; Rose et al., 2021b; Sparrow and Howard, 2021). The history of technology has shown that, in addition to the desired effects of socio-technical transitions, unintended side effects—often hardly calculable and difficult to control—occur as well. Historically, digitalization represents another major evolutionary step in a series of highly significant stages of technological progress in agriculture. Mechanization industrialized agricultural production (Rasmussen, 1982), and later, in the 1950s, the "green revolution" was launched, driven by new technological possibilities of agro-chemistry and agro-genetic engineering including chemical fertilizers, agrochemicals, vaccines, and genetic modification. While this technological progress led to enormous yield increases and improved efficiency, it was also connected to a wide range of unintended side effects, including environmental consequences (Singh, 2000). With regard to the digital transformation, it is not unlikely that certain socio-technological developments may lead to significant societally undesirable consequences. To date, however, the associated risks of digitalization along the agricultural production chain have been poorly understood, analyzed, and assessed (Rijswijk et al., 2021; Rose et al., 2021a; Scholz et al., 2018; Sparrow and Howard, 2021).

Emerging scholarly work indicates that digitalization is associated not only with opportunities but also with a number of possible undesirable changes, risks, and increasing vulnerabilities (Bronson, 2018; Eastwood et al., 2019; Fleming et al., 2021; Martens and Zscheischler, 2022). These include the further deepening of inequalities (Regan, 2019) through unequal access to new technologies caused by farms' differing financial capabilities (Fleming et al., 2018), power shifts and concentrations in favor of a few global agro-suppliers and tech companies (Klerkx and Rose, 2020; Trendov et al., 2019). There are also concerns about risks related to the misuse of data and the rise of data asymmetries: while farmers disclose personal farm-management data, they know little about how these data are stored and used, and whether they have any control or say in the matter (Jayashankar et al., 2018). Furthermore, increased digitalization leads to more complex technical systems, which may increase vulnerability to internal system failures (Ross et al., 2013), and could attract malicious actors aiming to compromise the cybersecurity of digital systems. In addition, digitalization can impact rural employment patterns, for example, through a decrease in jobs or new employment profiles (Rotz et al., 2019).

Thus far, these risks remain poorly understood. Recently published scientific work that critically examines the potential societal impacts of the digital transformation on agriculture (Cobby Avaria, 2020; Daum, 2021; Galaz et al., 2021; Lajoie-O'Malley et al., 2020; Rijswijk et al., 2021; Rotz et al., 2019; Sparrow and Howard, 2021) is based mostly on literature and document analyses or is conceptual in nature. Empirical studies that also highlight the ambiguities and uncertainties of future prospects as well as conflicting social views and valuations in dealing with the risks are still rare (Fleming et al., 2021; Regan, 2019; Salvini et al., 2020).

To ensure a sustainability-oriented digital transformation and to respond to ethical concerns that accompany the multitude of digital technologies many authors argue for the application of a responsible research and innovation (RRI) approach (Eastwood et al., 2019; Rijswijk et al., 2021; Rose et al., 2021a). Despite several differences in conceptualization, most RRI approaches follow the core principles of anticipation, inclusion, reflexivity, and responsiveness, often referred to as the AIRR framework (Owen et al., 2013). Such a framework includes the anticipation of future societal consequences of technologies and innovations as well as reflections not only on the desired and undesired impacts but also on one's own role and activities and the co-design of solutions to mitigate undesired effects. This follows the idea that an ex-ante evaluation of the unintended side effects and risks of digitalization in agriculture and critical analyses and discussions of underlying causes, mechanisms and possible development pathways make it possible, in the sense of prospective risk and sustainability management, to develop (policy) adjustments at an early stage and to initiate accompanying innovations that aim to exploit the social, ecological, and economic opportunities and potentials of digitalization in as optimal a way as possible.

However, Rose et al. (2021a) have pointed out that there is still little empirical anticipatory work on digital transformation in agriculture that includes a wider spectrum of stakeholders. Furthermore, transforming knowledge from anticipation processes into responsive action, thus bridging the gap from anticipation to responsiveness in terms of RRI, remains a major challenge (Rose et al., 2021b). This paper seeks to address these gaps.

In the following, we present the process and the results of the two-year transdisciplinary project DiDaT.[1] The aim of the transdisciplinary process was to jointly anticipate unintended side effects and identify perceived risks of the digital transformation in Germany by involving stakeholders representing a broad spectrum of societal interests. Furthermore, a central goal of the process was the co-development of socially robust orientations (SoROs) for the responsible use of digital data and technologies and, thereby, to identify perspectives of the anticipated knowledge toward responsible action. The process was structured along four guiding questions (Q1-Q4):

Q1: What are the unintended side effects, perceived risks and vulnerabilities caused by digitalization and digital data use in agriculture?
Q2: What general underlying mechanisms can be identified that lead to these unintended side effects?
Q3: What are the goals and conflicting objectives of different groups of actors that guide the management of these risks?
Q4: Which "socially robust orientations" (SoROs) for the responsible handling of digital data and technologies can be co-developed?

[1] https://didat.eu/homepage.html.

In this article we use the terms "digital transformation" and "digitalization". In line with Rijswijk et al. (2021), we define digital transformation as a fundamental and ongoing socio-technological change process in which digitization and digitalization increase over time. Digitization describes the process of converting analogue information into digital form. In contrast, digitalization means "the socio-technical processes surrounding the use of (a large variety of) digital technologies that have an impact on social and institutional contexts" (ibid.).

## 2. Identifying risks arising from digital data use in agriculture – theoretical considerations

Risk analyses refer to future developments that are difficult to grasp objectively and deal with great uncertainties, complexities, and ambiguities (Renn et al., 2011). Any estimation of probabilities that a particular negative event will occur often encounters the problem that it remains uncertain. In risk research, then, we speak of vague or ambiguous risks (ibid.). However, predicting the occurrence of an event is not only difficult and uncertain, but in addition, the extent of potential negative effects can be unknown. What is considered a negative unintended side effect and how strong this assessment is, depends on the personal interests, attitudes, values, and priorities of the assessor.

From the perspective that risk is an evaluation function of potential and uncertain losses (Scholz and Tietje, 2002), theories of subjective risk perception, such as the psychometric approach to risk perception, have evolved (Slovic et al., 1986). This cognitive-science approach states that risk perception is based on features of risk and individual characteristics such as novelty, knowledge, equity, control, voluntarity, dread, and catastrophic potential. In this context, a distinction must be made between the construction of a partially evidence-based risk assessment (which also includes expert judgments) and the subjective risk perception of laypersons. Scientifically based risk assessments often differ because, for example, they may include different parameters (the model of the risk situation differs), consider the findings of different experts with different assessments, follow different paradigms, make different assumptions, etc. In general, these decisions made in risk assessment (e.g., selection of certain parameters) can be reconstructed and justified. In contrast, the subjective, intuitive perception of risk shows a much wider range of variation depending on emotional concerns (Grasmück and Scholz, 2005) and (dis)trust with respect to the source of the risk (Siegrist et al., 2010).

Risk assessments may differ not only between different scientific analyses or between scientific and public assessments but also between different societal groups (Jenkins-Smith and Smith, 2019; Schwarz and Thompson, 1990; Wildavsky and Dake, 1990). Cultural theorists explain the different views of risks by different actor groups by the social construction of risks, arguing that risks are socially selected and constructed "to serve the social relations of those perceiving and analyzing them" (Johnson and Swedlow, 2021). Thus, views of risk and management are not solely or primarily related to "real" or "perceived" properties of risks but instead decisively biased by social relationships and institutions in groups (Tansey and Rayner, 2010). Cultural theorists argue that "social relations or institutions always come first, with risks filtered, selected, and assessed through cultural biases arising from the need to justify and defend those relations" (Johnson and Swedlow, 2021).

Furthermore, risks are political (Douglas, 1997; Schwarz and Thompson, 1990) and related to the question of adequate handling, weighing acceptability processes between their benefits and risks (Renn et al., 2011), in addition to ethical conflicts in relation to different actors' values as well as different vulnerabilities that must become subjects of a negotiation process. Consequently, a risk assessment is only part of the overall benefit (or utility) assessment. An overall assessment is produced when the positive impacts as well as the negative impacts are integrated.

In this paper, we distinguish between the terms "perceived risks" and "anticipated negative events" that cause these risks (Aven, 2011; Scholz et al., 2012). We define the latter as unintended side effects (unseens) that are judged undesirable. By contrast, perceived risks represent the assessment of these uncertain anticipated negative events with regard to potential losses and the probability of their occurrence (for an overview of key concepts, see Box 1).

Looking at risks and the adaptive capacities of a socio-ecological system to cope with negative events and potential losses allows an understanding of different vulnerabilities and, thereby, enables a forward-looking, sustainability-oriented shaping of digitalization and the use of digital data.

## 3. Methodology: The transdisciplinary research design of the DiDaT project

As described above, there is no objective measure for determining risk or vulnerability. On a societal level, risk management is subject to socio-political weighing and negotiating processes, especially in the case of potentially systemic effects, as in the case of the digital transformation. These considerations justify the requirement of a transdisciplinary research design. Due not only to a high level of uncertainties regarding the predictability of future developments and simultaneously complex interactions but also the divergence of normatively shaped worldviews and ethics for dealing with the different development options, the DiDaT project initiated a two-year transdisciplinary learning process involving representatives of different key stakeholder groups and scientists from different disciplines.

We define transdisciplinary (research) processes as those that relate a targeted interdisciplinary process with a multi-stakeholder discourse. The involvement of non-academics distinguishes transdisciplinarity from interdisciplinarity, the high degree of knowledge integration from multidisciplinarity (Zscheischler and Rogga, 2015). Transdisciplinarity is based on mutual learning processes among and between science and practice that follow the principles of "equal footing" among the actors involved, the "acceptance of otherness," and equivalence for coping with complex, societally relevant, real-world problems. The integration of different forms of practical and scientific knowledge is highlighted (Lang et al., 2012; Scholz, 2020; Scholz and Steiner, 2015; Zscheischler et al., 2014; Zscheischler and Rogga, 2015). This type of transdisciplinarity postulates that mutual learning and the committed involvement of practitioners resulting in equal eye level and co-responsibility call for authentic co-leadership between science and practice.

### *3.1. The DiDaT project: Integrating different types of values and knowledge*

The DiDaT project is the follow-up to a European Expert Roundtable on unintended side effects of digitalization that took place in 2017 (Scholz et al., 2018). This roundtable revealed the need to focus on the identification, analysis, and management of vulnerabilities and unseens emerging from the socio-technical digital transition to shape a sustainability-oriented digital transformation (ibid.).

The aim of the transdisciplinary DiDaT project was to develop a white paper on the responsible use of digitalization and digital data. The central output of the two-year mutual learning process between science and practice were socially robust orientations (SoROs) (Scholz and Steiner, 2015) that should help to avoid the negative effects of digital data use on important, sensitive subsystems in Germany and beyond. SoROs integrate knowledge and values. They represent jointly negotiated and co-developed orientations for how to further manage potential risks and are statements that have been - despite many different views - accepted by all actors involved and that can be seen as the major outcome of a transdisciplinary process (further explanation of the concept "social robustness" can be found in Box 2).

Therefore, DiDaT initiated transdisciplinary processes for seven different subsystems (e.g., health, mobility, social media, agriculture).

**Box 1**
Overview of key concepts, their distinctions, and their interrelations (Aven, 2011; Scholz et al., 2012)

**Unintended side effects**: unwanted, untargeted consequences caused (in this paper) by digitalization and digital data use in agriculture. These can be judged as positive or negative. In this paper, we denote negative unintended side effects as "**unseens"** as they may be unknown or unintentionally or intentionally overlooked.

**Anticipated negative events:** those unintended side effects that lead to risks and become identified by a process of anticipation.

**Risk:** an evaluation function of exposure and sensitivity to **anticipated uncertain negative events.** This includes an uncertainty assessment (usually performed by probabilities) of becoming exposed to an anticipated uncertain negative event (exposure) and an evaluation of potential losses (sensitivity). We use the term "**perceived risks**" to acknowledge the subjectivity of individual risk assessments.

**Vulnerability:** we define vulnerability as a complementary concept to resilience and as a function of risk and adaptive capacity. Adaptive capacity means the capability to take actions in order to change or mitigate a given risk.

**Box 2**
The concept of social robustness

The term "socially robust" is a central concept in "Rethinking science" (Nowotny et al., 2001). It describes a new quality of knowledge that goes beyond purely scientific criteria (such as reliability) and increases the relevance of scientific knowledge through "contextualisation". At its core, it is about linking scientific knowledge with "social and political concerns, values and interests of the lay public" (Weingart, 2017). Weingart (ibid.) further attempted to specify the underlying epistemological issue of socially robust knowledge, which is "how democratic procedures of representation and decision-making can be reconciled through compromise on the one hand and the credibility, reliability and quality of scientific knowledge claims on the other". The notion of robustness has been further elaborated by the concept of robust statistics signifying "insensitivity to small deviations from the assumptions" (Huber, 2004). Social robustness is thus a characteristic that knowledge should have when seeking solutions to problems involving conflict, uncertainty and ambiguity. Knowledge should be valid not only "inside but also outside the laboratory", which may be achieved through the participation of an extended group of experts in the knowledge production process (Gibbons, 1999). Based on this, the concept of socially robust orientations was developed in transdisciplinary research (Scholz and Steiner, 2015). It relates both to the robustness of arguments and explanations, and to the robustness of use and application of SoROs in real-world contexts as a means of resilience management.

These seven subsystems, which we call "vulnerability spaces", were viewed as particularly vulnerable with respect to the use of digitalization or a comprehensive use of digital data. In this paper, we focus on the results for the "vulnerability space" of agriculture.

The transdisciplinary risk analysis further combined a social-science constructivist approach with a realist, functionalist approach as it focused on i) the perceived risks, ii) the explanatory patterns and rationales regarding causes and mechanisms for the emergence of risks and vulnerabilities (i.e., different types of knowledge), and iii) different goals and conflicting values guiding the management of these risks. With regard to the latter, the transdisciplinary process sought to provide iv) socially robust orientations (SoROs) to address the perceived risks in societally acceptable and responsible ways.

### *3.2. Participating stakeholders and scientists*

The transdisciplinary approach of DiDaT aimed to integrate different forms of knowledge, including scientific knowledge, from a variety of disciplines as well as practical, experiential knowledge from practice and different societal perspectives and interests. Thereby, it built on the knowledge of the role of social group affiliations in risk assessment and sought to ensure that biases (e.g., judgment bias, cultural bias) associated with them were mitigated in the risk analysis of the digital transformation in agriculture. Thus, it included multiple perspectives of diverse actors and interest groups along the agricultural production chain in order to "take advantage of how each culture defines problems and solutions" (Johnson and Swedlow, 2021). There are different types and functions of stakeholder involvement. In DiDaT, we combined a knowledge- and competence-oriented approach ("functionalist type") with a legitimacy- and interest-oriented approach ("democratic type") of involvement (Mielke et al., 2016, 2017).

Running a transdisciplinary project on digitalization in agriculture was suggested by the German Nature and Biodiversity Conservation Union (NABU). The selection of stakeholders was based on interviewing seven of the nine experts of an Expert Hearing and approximately six additional scientists and practitioners. Attention was paid to ensuring a balanced representation of various interest groups. Stakeholders were classified along the common categories: polluter/originator, affected parties, and central groups involved in regulatory processes (Bryson, 2004). In regard to science actors, the aim was to find representatives of the most-relevant scientific disciplines. Reliability and a balance in stakeholder composition were ensured through an iterative and collaborative-discursive procedure: the process of stakeholder analysis and the identification of unseens underwent several loops.

Finally, a total of six representatives each from science and practice were involved. On the practice side, the German Farmers' Association (DBV), the largest professional German association of farmers, with more than 80% of all German farms as members; the German Agricultural Society (DLG), which aims to increase knowledge transfer to promote quality in the agricultural and food sectors; and an organization promoting organic agriculture (FiBL) represented a wide range of farming interests and knowledge. Other participants included digitalization experts from an international agricultural corporation (BASF), the German association for agricultural machinery producers (VDMA), and a representative of a large nature-conservation organization, the Nature and Biodiversity Conservation Union (NABU). In addition, scientific disciplines were iteratively identified and, accordingly, scientists involved in environmental sociology, agro-ecology, crop production, information technology/software, sustainability sciences, systems engineering, and spatial planning.

### 3.3. The steps of the transdisciplinary process

The process went through a number of stages and followed guiding principles for transdisciplinary research processes commonly described in the literature (Lang et al., 2012; Scholz and Steiner, 2015). The multistage process underwent iterative adjustments at each stage (see Fig. 1).

1) **Initiation phase:** In a first phase of DiDaT, agriculture was defined as an important "vulnerability space" (i.e., a subsystem of Germany which became subject of a transdisciplinary learning process on negative side effects of digitalization) among six others. The topic was described generally, system boundaries roughly predefined, and first important stakeholders named.
2) **First stakeholder conference:** Stakeholders who were initially identified as particularly relevant (see above) in regard to their understanding of the digital transformation in agriculture were invited to participate in a first stakeholder conference. During the event, guiding questions and system boundaries were jointly defined; a first screening and discussion of potential unintended effects of digitalization (unseens) along the agricultural value chain took place and was followed by the construction of a system model and the identification and analysis of further relevant key stakeholder groups.
3) **Concept draft for white paper:** Following the first stakeholder conference, the results of the group discussion during that event were documented and synthesized in a first rough concept draft of the white paper. With regard to the identified unseens, a joint identification and discussion of causalities of these unseens was initiated. Interviews with experts complemented this process.
4) **Stakeholder analysis:** The stakeholder analysis was a continuous and iterative process as described above (3.2). One milestone was a half-day workshop in 12/2019 in Berlin (presenting a rough plan which received multiple reviews), where we systematically reviewed the previous composition of stakeholders involved and identified perspectives and/or actors that were still missing using an "unseen x stakeholder" matrix.
5) **Second stakeholder conference:** The second stakeholder conference was the start of an in-depth collaboration (based on a fine plan which received multiple reviews) between actors from practice and science. The unseens identified previously were discussed and supplemented with others. Subsequently, four working groups in which scientists and practitioners were equally involved were established; these groups focused on four impact areas (agro-ecological impacts,

| Methodological Step | Details | Time |
|---|---|---|
| 1 – initiation phase | • research question and system boundaries<br>• (1st Stakeholder Analysis) | Jan-Apr 2019 |
| 2 – 1st stakeholder conference | • beginning of formation of Td team;<br>• joint problem definition and specification of research question;<br>• co-design of research by defining unseens | June 2019 |
| 3 – concept draft for White Paper | • documentation of results from 1st stakeholder conference;<br>• joint identification of causalities of unseens;<br>• interviews with additional experts | July-Sep 2019 |
| 4 – stakeholder analysis | • document analysis (snowball method);<br>• group discussion on relevant stakeholders | Oct-Dec 2019 |
| 5 – 2nd stakeholder conference | • identification of most relevant impact areas;<br>• final stakeholder selection for the whitebook chapter;<br>• splitting into working & writing groups for 6 sensitive subsystems | Jan 2020 |
| 6 – working in co-author teams | • analysis and discussion of unseens, underlying causes, objectives in handling risks and measures for each subsystem;<br>• documentation in form of a report (SI) | Mar-Sep 2020 |
| 7 – synthesis | • co-authored, discussed and balanced synthesis by socially robust orientations for the white paper | Oct-Dec 2020 |
| 8 – review and revision | • transdisciplinary review and revision of the white paper | Dec 2020 – Jan 2021 |

**Fig. 1.** Process flow and main project steps in the two-year transdisciplinary process of co-writing a white paper (including steps of goal definition, selecting key stakeholders, meetings, data, and products).

data rights and market concentration, automation, food security) identified as most significant by the stakeholders.

6) **Working in four transdisciplinary co-author teams:** In the following months, the working groups functioned as co-author teams seeking to develop an in-depth understanding of the i) unseens, ii) their underlying causalities, iii) different goals and conflicting objectives, and iv) socially robust orientations (SoROs) for addressing the identified risks. The results of this challenging process of negotiation and co-production of knowledge were documented for each unseen in a paper supplementing the white paper, which we called Supplementary Information (SI) (Brunsch et al., 2021; Reichel et al., 2021; Scholz et al., 2021; Zscheischler, Rogga, et al., 2021).
7) **Synthesis in a white paper:** On the basis of these four SIs (Supplementary Information), a white paper was co-authored to integrate the perspectives and knowledge of all the actors involved from science and practice (Zscheischler, Brunsch, et al., 2021).
8) **Review and revisions of the white paper:** Before publication, the white paper and the four SIs underwent an external review and validation process receiving 22 reviews, (each from four perspectives: science, practice, sustainability, and public administration). Comments and suggestions were adopted and the manuscript revised.

### *3.4. Data collection and analysis*

The results presented in this article are based on a triangulation of two different data collection and analysis methods. These are, on the one hand, the transdisciplinary group process of knowledge integration and, on the other hand, an ethnographic qualitative meta-analysis.

Knowledge integration is at the heart of transdisciplinary processes. The aim is to develop a more comprehensive understanding of a complex real-world problem by integrating disciplinary and stakeholder knowledge (Bammer et al., 2020; Zscheischler and Rogga, 2015). In the present study, this was facilitated by using the integration method of a “boundary object” (Bergmann et al., 2012) in the form of collaboratively writing a white paper. The integration process was characterized by an iterative rewriting process with several loops of discussion and negotiation between the actors involved. This process can be viewed as a synthesis of data collection and analysis. Some perspectives and knowledge were not shared by all actors and were vehemently rejected, which is why the white paper contains mainly consensual knowledge. Therefore, we complemented these findings with the results of participant observation applying central principles of ethnography (Bryman, 2016; Lüders, 2004). The ethnographic approach focused on analyzing the social interactions, the different perspectives and disagreements within the co-author teams and the whole group. It was conducted by the first author, who was also the facilitator of the transdisciplinary process. The role of the facilitator allowed for full access and participation as a full participant (observer) along the whole process. Data was collected through observations on the group discussions, informal conversations with individual actors and various drafts of the jointly drafted documents (White Paper and SIs) and associated comments. Field notes and systematic observation protocols were taken during and after each event (e.g. workshops, talks, co-authors’ team meetings, status conferences). Observations were structured along the focus on all relevant information related to the research questions (Q1-Q3, see introduction) and furthermore on the social interactions of the actors involved in the course of the discourse on unintended side effects and associated perceived risks.

## 4. Results

The results section is structured along the four articulated guiding questions of the transdisciplinary process (Q1–Q4; see introduction).

### *4.1. Perceived risks and vulnerabilities due to digitalization in agriculture*

During the transdisciplinary learning process, the stakeholders identified four areas where unintended side effects that cause perceived risks and vulnerabilities are expected as a consequence of the major changes brought about by the digital transformation in agriculture. These include impacts on i) agro-ecology, ii) data rights and market concentrations, iii) changing knowledge and decision-making competencies through digitalization, and iv) food security (see Table 1). In the following, we describe the summarized perspectives that resulted from the transdisciplinary process.

#### *4.1.1. Agro-ecological impacts of digitalization*

Despite digitalization’s significant potential for agriculture that is more environmentally sound, some participants expressed concerns about negative agro-ecological impacts. These included: i) a further progressive reduction of biodiversity and negative impacts on environmental assets; ii) potential negative impacts on soil structures and soil fertility; iii) possible unfavorable changes to established cultural landscapes; and iv) negative impacts on the resource and ecological balance. These concerns were justified by the fact that the use of digital data and technologies tends not to be optimised for maximising sustainability effects, but mostly for productivity alone. For example, the development of light and smart field robots could lead to the cultivation of previously fallow land. Ecological residual niches would then be in danger of disappearing. At the same time, there is a trend towards ever larger and heavier agricultural machinery, which promotes soil compaction with negative consequences for soil erosion and the water balance. There were also worries about rebound effects or changes to the cultural landscape.

#### *4.1.2. Data rights and market concentrations*

Various actors expect that digitalization in food production will cause an acceleration of structural changes in agricultural production, processing, and trade. In addition to the traditional actors, they see new global players with high-level digital competence and financial power emerging. The large global players in the agricultural machinery, seed, and chemical industries generate large and detailed databases via the provision of machinery, consulting, and services in the course of planning and executing processes. Different groups of actors have different views about who is allowed to use what data, for example, in the case of machine data. A controversial topic among actors is the extent to which there is a need for sector-specific legal regulations to be developed and legitimized by means of participatory and transdisciplinary processes. The market power of stakeholders in the value chain is considered highly imbalanced. There are actors and oligopolists who are actively engaged in finding models for data sharing, while others stay out of the discussion. From a competition-law perspective, this may result in problematic farm dependencies. The competitive advantages of having access to a large amount of data across the food system enable new value creation potential and collaborations. However, whether and how this accelerates the formation of oligopolies and monopolies should also be critically considered.

#### *4.1.3. Automation, changing knowledge, and decision-making competencies*

There is consensus amongst the actors that the digitalization of agriculture enables the optimization and automation of agricultural production. Farm planning, organization, and management are largely covered by automation. At the mechanization level, autonomously operating machines (robots) will increasingly achieve a new quality of automation. Many potential opportunities exist, and numerous positive changes are occurring, such as the facilitation of work, improved decision-making, and increased efficiency. Digitalization and the gradual use of digital farm models (e.g., the digital twin) are changing the skill profile of the farmer. Potential risks and limitations of the farmer’s decision-making competencies arise as many steps of the

**Table 1**
Overview of causal factors of digitalization and digital data use for the four identified areas of unseens (unintended side effects). All data refer to possibilities without quantification.

| Unseens | Agro-ecological impacts | Data rights and market concentration | Automation, changing knowledge, and decision-making competencies | Food security |
|---|---|---|---|---|
| **Causal factors** | Insufficient digitalization<br>– Insufficient exploitation of the potential of digitization<br><br>Loss of biodiversity<br>– Use of digital data is not optimized to “maximize” biodiversity;<br>– Leveling of soil conditions in arable land and loss of marginal subsites<br><br>Loss of ecological niches<br>– Trend toward light and smart field robots<br>– Use of previously inaccessible fallow land by means of field robots<br><br>Soil compaction (soil erosion, unfavorable for water balance and nitrogen losses)<br>– Trend toward larger machines continues<br><br>Changed resource and ecological balance<br>– Rebound effects due to increased energy and material use<br><br>Changes in cultural landscapes<br>– Adaptations of the landscape to technologies;<br>– Influence on field sizes;<br>– Loss of fringe structures and niche areas;<br>– Changed field path infrastructures;<br>– Homogenization of management practices leads to decreased diversity in agricultural landscapes | Trend toward the formation of monopolies<br>– Trend toward smaller, more innovative companies being taken over by large companies;<br>– Agreements between a few players (e.g., on interoperability of systems);<br>– Exclusivity of data/market access<br><br>Farmer’s dependence on agricultural and data corporations increases, restricting his/her sovereignty<br>– “Lock-in” effects (poor portability of data);<br>– Uniqueness of services/lack of choice (and freedom of decision) in the market;<br>– Some services linked to data sharing;<br>– Lack of knowledge about (open source) offers<br><br>Control over the farmer’s own data decreases<br>– Lack of exportability of data/lack of control over data/lack of awareness (“farmers actually have the upper hand”?);<br>– Lack of qualification/knowledge to exercise data sovereignty;<br>– Lack of transparency in services | Changed human–machine interactions<br>– System complexity increases and possibilities for intervention become more difficult due to lack of “digital literacy”;<br>– Reduced human intervention;<br>– Importance of human labor decreases;<br>– Work is changing into a form of “automation work”<br><br>Changed knowledge and judgment skills<br>– Virtualization leads to loss of visual, auditory, and tactile access to events;<br>– “Automation bias” limits decision-making and judgment skills;<br>– Practical knowledge is lost through “disuse”<br><br>Restrictions at the decision-making level of the farmer<br>– Farm machinery regularly collects data on the farm and passes it on to platform operators;<br>– The farmer becomes transparent, influenceable, and more dependent on the platform operator;<br>– Dependency leads to limited freedom of choice for the farmer, who is bound to the services of the platform operator;<br>– Restricted choice leads to a decrease in diversity in agricultural landscapes | Increasing susceptibility to errors and faults<br>– Increasing complexity of digital systems;<br>– Hacker attacks;<br>– Dependence on external factors increases<br><br>Monopoly tendencies<br>– Global technology corporations discover agriculture as a field of action;<br>– “Are Microsoft/Amazon able to do agriculture?“;<br>– Collusion among market participants;<br>– No transparency rules<br><br>“Digital divide” continues to grow<br>– Unequal access to knowledge;<br>– Unequal financial resources;<br>– Global North versus Global South<br><br>Wrong price signals on/speculation with agricultural commodities<br>– Market prices influence decisions and the farmer’s cultivation behaviors;<br>– Digital systems optimize for economic success<br><br>Decrease in the robustness of the food system<br>– Optimized systems lose redundancy and diversity;<br>– Digital systems optimize for specific crops;<br>– Decrease in diversity of individual management practices |

digitalized production chain are taken over by external parties. Stakeholders have different views and expectations with regard to the role and function of farmers and the knowledge and decision-making competencies they now require.

Some stakeholders and scientists involved in the transdisciplinary process have a more critical perspective. They fear a decrease in knowledge and judgment skills, increasing dependence of the farmer leading to external actors having greater influence on his or her decisions, and a monotonization of work processes. In contrast is the entrepreneurial view of agriculture: Robots, digital systems, and programs can free farmers from routine work, making it possible for them, in terms of time and information, to devote themselves, together with advisors and service providers, to the essential agronomic tasks on the farm. A third picture is an extension of the second perspective. Here, greater importance is attached to digital competencies. The farmer is conceived as a kind of "digital biosystem manager" who combines analog knowledge about animals and plants with knowledge about their representation on the digital twin. In this variant, which, at least in the case of smaller farms, may not be in the near future, the knowledge of how the algorithms work (e.g., rule-based deterministic, stochastic, types of self-learning, etc.) and the ability to interpret the quantitative data and qualitative results play important roles. The data collected on the farm represent a kind of trade secret for the farmer, for whom the publication of such data means the loss of a competitive advantage and, thereby, establishes his or her motivation to maintain data sovereignty. This is important in the discussion of what data remain freely available (open access data) and at the disposal of the company.

#### *4.1.4. Food security*

Global digital data have great potential not only to detect food shortages worldwide at an early stage but also to further expand global food security through improved planning, decision-making, and risk management. However, unintended consequences of digitalization (unseens) could result from information asymmetries, false price and market signals, a lack of internalization of (environmental) costs, and new opportunities for genetic manipulation. The latter can contribute to a reduction in crop and livestock diversity, for example, to avoid vulnerabilities from resistant pests.

### *4.2. Causes and mechanisms for the emergence of risks and vulnerabilities*

The origins of the perceived risks have been explained through a number of underlying mechanisms and causal factors. Table 1 includes all the factors discussed in the process and contributed (and strongly justified) by all four transdisciplinary co-author teams (see 3.3., Step 6).

In the following we specify the synthesized causal factors along five superordinated categories that describe mechanisms for the emergence of risks and vulnerabilities.

#### *4.2.1. Technological transformation through digitalization*

First, there are the specific changes brought about by digitalization itself and its technological mechanisms. These start with breeding optimization of crops and animals; more efficient use of nutrients and inputs (such as pesticides); an increasingly digitalized, automated work environment requiring less human labor; and the potential for more environmentally friendly and welfare-friendly animal, crop, and food production.

New digital technologies and sensors enable the automated collection of large amounts of data on (centralized) platforms. The analysis and use of these data enable the optimization and automation of agricultural production processes. These include operational planning, organization, and management. By networking agricultural machines with each other and with (central) data platforms, a new quality of automation can be achieved, for example, in the area of control automation or autonomously acting machines (robots, swarm technologies). The analysis of vast amounts of data (big data) enables digital decision-making processes that are geared toward specific goals (e.g., optimization for profitability or for agro-ecology) and, thus, support "improved" decisions.

There are opposing assessments on the question of what concrete agro-ecological effects the digitalization of agriculture will have and how potential opportunities for relieving the burdens on the environment will actually be used. On the one hand, a continuing trend in the development of large agricultural machinery that is increasingly automated can be observed. On the other, there is the potential related to the development of small, lightweight field robots that may be used in swarms.

#### *4.2.2. Restructuring the value chain: new players and global networking*

Associated with these technological developments is the ability to collect, process, and correlate vast amounts of data. The use of digital data gives rise to new business models, but these are not yet well-understood. Data and the information that can be generated from it are and will continue to become an increasingly important competitive factor.

Often, the farmer has no access to the data collected on his or her farm and does not know what it is used for. There continues to be a lack of "transparency rules" that would enable farmers to gain data sovereignty. The provision and collection of farm data on central data platforms can lead to a dependency on agricultural and data corporations.

New players with high-level digital literacy and financial power are beginning to take an interest in agri-food data. These include large, global companies (Amazon and Google, among others), which pose a challenge for political governance due to a lack of national ties. It is possible that digitalization and the increasing interconnectedness associated with it will support globalization tendencies that may lead to oligopolization in the food system.

#### *4.2.3. Market mechanisms: market concentration, new dependencies, and optimization*

Digitalization has the potential to further drive already existing trends toward market concentration. The varying adaptability of market participants to the digital transformation can lead to smaller companies being taken over by larger ones and structural change, thereby, being reinforced by digitalization.

Agreements among players with significant market shares (for example, on the interoperability of systems) also significantly restrict access to the market for new players and can make competitive conditions more difficult for smaller companies. The increasing dependence on data and its simultaneous lack of access by farmers (who often do not have access to data collected by machines) and the lack of portability of these data, as well as the lack of interoperability between different provider systems, can lead to "lock-in" effects that make it difficult to dissolve contracts and can lead to hardly resolvable dependencies on digital service providers.

Many market-based processes are oriented toward increasing efficiency and economic optimization. Increasing rationalization and optimization through digital decision-support systems can unilaterally support these mechanisms. This leads to restriction in the diversity of products and production processes. On a global scale, this also has the effect of reducing the diversity of crop species, which is considered critical from an agro-ecological perspective, and poses a potential threat to the resilience of agricultural production systems.

#### *4.2.4. Mechanisms in decision support*

Linking agricultural machinery with different data sets via centralized data platforms (clouds) enables a new level of automation which also affects decision-making processes. An uncritical and overconfident attitude by farmers in regard to the capabilities of digital systems may lead to a situation where their own considerations, decisions, and judgments are too quickly withdrawn or discarded and subordinated to the decision made by a machine and, thereby, reducing their management and decision-making competences in critical situations.

There is also the possibility of automated decisions being made by algorithms and without a farmer's input. That new technologies and algorithms as well as (the selection of) training data sets for the development of algorithms are based on value models with predefined indicators and rules must be taken into consideration. This normative dimension shapes automated digital decision-making processes. If all automated systems follow the same logic and optimization goal (e.g., increase efficiency, reduce jobs), the diversity of management practices can be reduced. However, lock-in and dependence on specific platforms, services, and farm machinery can also limit the farmer's freedom of choice.

#### *4.2.5. Increasing system complexity: new knowledge requirements and adaptive capacities*

The changes associated with the digital transformation require adaptations on the part of farmers and all associated actors in order to remain competitive and, thus, in the market. The changed working conditions offer farmers a number of facilitations; however, digitalization also requires and enables new knowledge for the successful management of the agricultural business. The handling of modern agricultural machinery and the sophisticated management of operational processes via farm-management systems require an altered qualification profile of the farmer. This includes the knowledge and skills to interpret data and critically evaluate results from data analyses to assess the quality and reliability of decision-support information.

With the increasing complexity of digital systems and the related and growing dependence on data come the development of new types of system susceptibilities to failures and errors. At the same time, this complexity, along with a lack of transparency and knowledge, makes it more difficult for farmers to intervene when systems malfunction.

Digitalization leads to a new quality of information exchange between the farmer, his or her means of production, and the production environment. There is a changed human–technology–environment relationship. Increasingly more sensors will replace the complex "analog" perceptions of humans. Coupled with historical information and predictions, digital information provides an improved basis for decision-making. Routines of action change and, as with any innovation, there is a possibility that "old"/traditional skills and knowledge will be replaced by new skills and knowledge. As a result, rarely needed but important knowledge can be lost through prolonged disuse.

Not only transparency in dealing with data but also problem awareness and knowledge on the part of farmers are essential prerequisites for sharing in the benefits of the digital transformation in the agricultural sector.

### *4.3. Goals and conflicting objectives that guide the handling of these risks*

The risks of digitalization were assessed quite differently and, sometimes, controversially by various agricultural experts. These differing perceptions gave rise to "risk conflicts" as well as conflicts in regard to the goals of different groups of actors in dealing with these risks. The contrasts here spanned the poles of entrepreneurial, market-oriented positions with somewhat technology-optimistic assumptions, on the one hand, and technology-skeptical, more critical voices on the part of various civil society groups (e.g., environmental, animal welfare, social groups), on the other.

In principle, overarching objectives at the level of society, such as an orientation toward the common good and sustainability, are generally shared and unanimously endorsed. These included a general agreement on the goals of food security and sovereignty as well as resource protection, biodiversity conservation, trustworthiness of data, and avoidance of dysfunctional and competition-critical data monopolies and new dependencies of farmers. However, not only how the exact design of these goals but also how the process operationalization (transformation knowledge) to achieve them should be conducted led to contentious discussions among the actors involved in the transdisciplinary process.

i) Economic-oriented and technology-optimistic perspectives:

Economic interests, constraints, and competitive pressures promote and accelerate technical progress. From a techno-optimistic perspective, new technologies can counter the negative consequences of previous technologies. Thus, the actors representing a business-oriented position saw digitalization as a "great opportunity" and as predominantly positive. They saw primarily the positive effects for the environment and the farmer, considered little need for regulation, and represented the following goals:

- To exploit the advances in digitalization as far as possible in order to better implement agro-ecological and animal-welfare ideas and goals of society and to find an appropriate balance between agro-economic and ecological goals;
- To use the potential of digitalization to significantly relieve farmers in their work routines, thus creating capabilities for other essential tasks;
- To support the exploitation of digital opportunities to increase yields and efficiencies (e.g., by saving inputs, facilitating documentation, and improving decision-making and farm management);
- To build competence for coping effectively with new types of errors (e.g., intuitive decision errors) and develop competence for using data; and
- To exploit and expand the competitive advantages of digitalization (e.g., by strengthening the position as a technology pioneer in global competition).

ii) Socio-ecological and techno-skeptical perspectives:

In contrast, there are techno-skeptical, socio-ecological positions that are concerned about the effects of digitalization in agricultural landscapes with regard to its ecological and social consequences. It is true that these actors also concede that digitalization has ecological optimization potential. However, they are skeptical about the extent to which these positive effects will occur automatically and without unintended consequences for nature and people. They fear a continuation of the trend of past technological developments in agriculture and, linked to this, increasing negative consequences. From this group of actors' perspectives, the following are central goals:

- regulating digitalization in order to promote the preservation and expansion of multifunctional agricultural landscapes as well as the protection, improvement, and restoration of biodiversity;
- preserving the diversity of farm structures while maintaining environmentally friendly agriculture that provides targeted environmental services;
- supporting farmers appropriately in their adaptation and competitiveness. In this context, dealing with critical aspects such as digital-incident management capabilities and avoiding major dependencies on (new) digital and industrial players through good data sovereignty management are important;
- establishing an enforceable set of rules for the allocation, access, and use of data at the national, international, and, where appropriate, supranational level in the field of agriculture and food; and
- establishing transparency and trustworthiness.

**Table 2**
Four socially robust orientations as a result of the transdisciplinary learning process.

| Area of risks and unintended side effects | Socially robust orientations for managing these risks |
|---|---|
| 1) Agro-ecological impacts | *"Whether and under what conditions and what negative agro-ecological impacts will result from the digitization of agriculture is largely unclear. On the part of environmental protection and nature conservation, there are concerns about negative impacts on biodiversity, environmental goods, ecological balance, soil structure, and cultural landscape. Concerted, independent research is needed to clarify whether these concerns are justified."* |
| 2) Data rights | *"Interpretive rules are needed on the question of who has access to agricultural operating and production data and how, and who uses or markets this data in a competitive manner. Attention must be paid to data sovereignty and the avoidance of excessive dependency on the part of farmers, as well as to the formation of (data) monopolies that endanger the resilience of agriculture. This requires participatory design processes with all central stakeholders."* |
| 3) Automation | *"Comprehensive learning forums (e.g., real labs) are needed so that agricultural stakeholders can actively shape digitalized automation and the value chain (IoT) and reflect on multiple sources of error/disruption. The questions of who should have access to which data, when, and how require the knowledge of the actors in order to enable, e.g., for agricultural data platforms, trustworthy structures and legal regulations for fair competition between the participants."* |
| 4) Food security | *"Information asymmetries between public-good-oriented actors and oligopolies with large databases, allow (in principle) misleading price signals or the unsustainable use of soils, crops, or livestock. Global open-source agricultural databases with basic data to monitor the multiple causes of critical yield dynamics support—in interaction with private-sector data from farmers and companies—resilient structures, innovations, and competition to maintain food security."* |

### *4.4. Socially robust orientations for dealing with the perceived risks*

In a final step of the transdisciplinary process, four socially robust orientations (SoROs) were derived for managing the risks of digital transformation in agriculture (see Table 2). Against the backdrop of the above-described different risk perceptions and different interests of the various actors to manage potential risks of digitalization, the SoROs represent jointly negotiated and co-developed orientations for how to further manage potential risks. SoROs are statements that have been accepted by all actors involved and can be seen as the major outcomes of a transdisciplinary process.

## 5. Discussion

The results have shown that, despite the numerous promises of digitalization for agriculture, a broad range of potential risks is perceived. These risks include effects on agro-ecological systems, on the one hand, and on the other, effects on social systems in terms of market concentrations, new power structures, information asymmetries, and new dependencies with potentially negative effects on food security. Many of the anticipated unintended side effects and the associated perceived risks support the findings of prior empirical work, for example from Ireland, Australia, and New Zealand (Eastwood et al., 2019; Fleming et al., 2021; Regan, 2019). However, we argue that we are not only complementing previous results with new findings from Germany. Our results are based on an intensive mutual learning and knowledge integration process over a period of two years that involved key stakeholders representing a broad range of different societal interests. Although this is in line with the highly advocated RRI principle of "inclusion," such processes have thus far been rare (Rose et al., 2021a). In addition, with the jointly developed SoROs, we offer an approach for how to transform the knowledge produced from a transdisciplinary anticipation process towards responsive action. This was identified as a major challenge when dealing with uncertain risks of the digital transformation (Rose et al., 2021b).

As is usually the case, risk perceptions vary greatly and are strongly dependent on the respective values, worldviews, and ethics of the various actors involved (Jenkins-Smith and Smith, 2019; Regan, 2019). Conflicts emerged from the special sustainability reference to agriculture (through the direct relationship between human–technology–environment). Different groups of actors link the concept of sustainability with somewhat controversial ideas and conceptions (Moore et al., 2014; Schneider et al., 2019). In Germany, an ongoing social discourse has become established with, sometimes, hardened lines of conflict and controversial views on the question of what "good" and "just" agriculture looks like (Nowack and Hoffmann, 2020). These lines of conflict were also observable between the actors involved in the transdisciplinary process. Despite these controversies, we were able to co-develop four socially robust orientations for dealing with the risks of digitalization and digital data use that were accepted by all actors involved (see Table 2). In a next step, we discuss the implications and relate them to the scientific discourse.

### *5.1. Socially robust orientations for dealing with uncertain agro-ecological Impacts*

Although there is great potential for agriculture that is more environmentally sound, some technology-skeptical stakeholders involved in this process also expect negative agro-ecological impacts of digitalization in agriculture. Currently, the dominant discourse emphasizes the ecological and economic benefits (Rose et al., 2021b). However, in contrast to this narrative, data collection and analysis in precision farming focus instead on inputs and production. The effects on externalities and losses of biodiversity have not been the focus of big data collection and analytics by large agribusinesses' technology thus far (Carbonell, 2016). Therefore, the extent to which widely heralded promises regarding the environmental effects of digitalization will finally play out is not yet known. Most studies have been based on experimental model predictions and fewer on observed impacts (Finger et al., 2019). The few available empirical studies on ecological effects indicate a reduction of GHG emissions and nitrogen losses, lower pesticide and insecticide applications, or water savings (Balafoutis et al., 2017). However, the results are highly case-dependent and variable since agricultural sites and cultivation practices differ widely. The magnitude of ecological effects remains largely uncertain (Finger et al., 2019). Consequently, the stated requirement for additional research on the environmental effects under varying conditions of data-driven farming is a main outcome of the transdisciplinary process (see Table 2). Looking ahead, we assume that it will depend on the design and optimisation parameters of the digital systems which agro-ecological goals are ultimately pursued and achieved (Sparrow and Howard, 2021).

The unseen of "agro-ecological impacts" was the most controversial element of the entire transdisciplinary discourse process. From a scientific perspective, that our current agriculture and food system is one of the main drivers of critical global environmental change is indisputable (Carpenter et al., 1998; Donald et al., 2001; Le Moal et al., 2019; Norris, 2008; Sánchez-Bayo and Wyckhuys, 2019). Therefore, the scientific community considers agriculture one of the most important fields of transformation of our time (Rockström et al., 2009). This perspective, on which there is scientific consensus, has not been shared by all stakeholders involved in the transdisciplinary process and has even been questioned by individuals. This skepticism of science can be observed increasingly in conservative circles, where scientific findings "on the basis of motivated identity-protecting cognition" are rejected (Lewandowsky and Oberauer, 2016).

### 5.2. Socially robust orientations regarding data rights and market concentration

Results demonstrated that a pressing area for action is the design of data use and access rights. Thus far, farmers typically have little or no access to the data collected on their own farms, nor do they know what happens to these data and how they are utilized. Farmers are severely restricted in exercising their data sovereignty rights (Jayashankar et al., 2018). In accordance with findings of other scholars, our study revealed a perceived tendency toward data monopolization and dysfunctional dependencies of farmers on large agricultural or data corporations (Carbonell, 2016; Fleming et al., 2021; Klerkx et al., 2019; Klerkx and Rose, 2020; Rose et al., 2021b)

Thus, models for "good" data-sharing have become a major factor in discourses on the digital transformation (Hardjono et al., 2019). Specific consideration must be given to how trustworthy structures can be designed on an industry-specific basis. However, considerations regarding greater transparency in digital products and services, improved interoperability between systems of different providers, as well as open-source offerings or so-called data alliances as a counterforce to monopolization were not equally supported by all actors. Because of the different interests of the stakeholders involved in the transdisciplinary process, achieving a fundamental agreement on the need for and design of legal regulation was not possible.

In this context, it must also be considered that regulatory measures may quickly become an obstacle to innovation processes and have unwanted effects (Rose et al., 2021b). As the digitalization of agriculture provides many potentials for more-productive and, at the same time, more ecological cultivation practices, the development of a suitable governance approach is a balancing act between exploiting the socially desirable potential for progress, on the one hand, and avoiding digitalization's undesirable side effects, on the other.

At the present time, national governments and various interest groups have different ideas about a suitable governance strategy, ranging from a "laissez-faire, industry-driven approach" to a "precautionary and preemptive strategy on the part of government" (Linkov et al., 2018; Martens and Zscheischler, 2022).

A particular challenge is the anticipation of future developments that can hardly be foreseen in disruptive innovation processes. The ongoing process of digitalization is characterized by constantly emerging business models that are based on data but are poorly understood in advance. In this regard, but also in accordance with the results of the transdisciplinary process and as part of an adaptive governance approach, an ongoing transdisciplinary monitoring, negotiation, and design process involving all central actors is required in order to discuss and co-develop such a legal framework (Renn et al., 2011). As previously advocated by a number of scholars (Daum, 2021; Rijswijk et al., 2021; Rose et al., 2021a), the principles of the RRI approach (anticipation, reflexivity, inclusion, and responsiveness) provide a suitable framework for guiding such a process. However, a major challenge will be how to turn knowledge from the anticipation process into responsive action (Rose et al., 2021b). With the development of SoROs, we offer a potential approach.

### 5.3. Socially robust orientations regarding smart automation and new knowledge

The digital transformation will lead to a new quality of automation in agricultural production (Shamshiri et al., 2018). Besides many beneficial effects, involved stakeholders assumed undesirable side effects on decisions and decision-making competencies. Still, consequences such as external manipulations, limited choices, and losses in decision sovereignty are hardly reflected in the scientific literature and, thus far, poorly understood. We argue that new knowledge (analytical skills) and adaptive capacities will be required, especially on the part of farmers. Training and informing farmers can be considered an important prerequisite for exercising data sovereignty. In this context, digital/data sovereignty is understood as the capacity of an individual farmer for self-determination and to "take actions and decisions in a conscious […] and independent manner" (Pohle and Thiel, 2020). This will require improved "digital literacy" and the critical management of digital technologies and data for farmers (Koltay, 2011). What exactly constitutes a farmer's specific digital literacy will and must be a subject of future research projects. Certainly, knowledge about the (economic) value of the data collected on their farms, critical reflections on the way algorithms work (e.g., rule-based deterministic, stochastic types of self-learning, etc.), and new skills to be able to interpret quantitative data and qualitative results will play important roles. Therefore, a full range of training, communication, and exchange measures at all qualification levels must be developed and implemented.

There are additional human factors that influence human interaction with automated and decision-making support systems. Studies of automatization processes have shown that automatization does not simply replace but rather changes human actions—often with unintended effects (Parasuraman and Manzey, 2010). One frequently observed phenomenon is "automation bias" (ibid.) resulting from an overestimation of the performance of automated decision aids and their perception as powerful agents with superior analytic capabilities (Lee and See, 2004); this may lead to decisions that are not based on an analysis of all available and relevant information. However, previous findings on automation bias come mainly from aviation studies and studies in health care (Parasuraman and Manzey, 2010). To what extent this phenomenon will also be relevant in automated decision-making support systems in agriculture that are based on big data remains a subject of future research activities. In this context, an additional research need for the relationship between "traditional" knowledge and new knowledge was identified. The automatization process changes the relations and interactions between farmers and their environment. It is assumed that, in the future, most operational activities will be left to machines, while farmers will increasingly be involved in "higher intelligence level" processes (Wolfert et al., 2017). There is a risk that much of farmers' tacit and experiential knowledge and skills (with regard to interactions of the soil–plant–animal system, optimal processing times, etc.) will hardly be needed and, thus, lost through prolonged "disuse" if decisions are constantly suggested or even made automatically (Ingram and Maye, 2020). "Use it or lose it" is a term commonly applied to a general phenomenon that can also affect farmers. In addition, new technologies and algorithms are based on value models with predefined indicators and rules (Fourneret and Yvert, 2020; Martin, 2019). This normative dimension shapes automated digital decision-making processes, and users should be well aware of this.

### 5.4. Socially robust orientations toward food security

Global food security became a significant subject of the DiDaT project, as the German government, in agreement with the FAO, stresses global responsibility dimensions regarding the food supply, such as the stability of availability and access and long-term intergenerational productive capacity (Borlaug, 2010; HLPE, 2020). In principle, global digital data have a great potential not only to detect food shortages worldwide at an early stage but also to expand global food security through improved planning, decision-making, proper institutional empowerment (Bondoc, 2018) and risk management. However, unintended consequences of digitalization (unseens) could result from critical information asymmetries (by data oligopolists), false price and market signals, a lack of internalization of (environmental) costs, and new opportunities for genetic manipulation, which is also a digital issue as the genetic code is genuinely a sequence of four digits (Scholz et al., 2018). The latter can contribute to a reduction in crop and livestock diversity and, for example, increase vulnerabilities from resistant pests.

In this context, too, the importance of a data archive in the form of an open-source database for “basic data” is being discussed. In the future, it will be necessary to develop and negotiate strategies, architectures, and concepts for the design of such a data platform with the participation of representatives of all stakeholder groups, also using transdisciplinary processes.

To realize the potential of open data platforms, all key actors in the value chain should have access to basic agro-data, via an open-source agricultural database that may be managed by a non-profit organization. This would avoid information asymmetries between actors, whose numbers might increase if oligopolists from the agro-supply chain were to gather data from farms and utilize them for competitive action. Such asymmetries can endanger food-price sensitive countries. Data asymmetry can be illustrated by the case of combine harvester. Yield data of any farm worldwide are automatically recorded and collected by combine harvesters and sent to the machinery producer. These data may be used on the food-yield commodity market for hedging, speculating (Andreasson et al., 2016; Chadwick, 2017; Fleming et al., 2021), and other purposes. Price peaks with subsequent undersupply for food-price-sensitive countries may be seen as causing a food-security issue. The food-supply chain is a sequence of steps (from fertilizers to seeds, chemicals, and machinery to trading), and each is controlled up to 80% by a handful of oligopolies (Mooney, 2018). Actually, based on the transdisciplinary discourse, the participants considered a strong information asymmetry of global agro-data as a possibility. Yet representatives of agro-oligopolies considered their own potential as too limited and considered instead large digital-infrastructure providers that enter the market.

The European agro-machinery industry stressed that agro-data (which are not relevant for competition) should become public (CEMA, 2000). There are strong efforts on the European level to differentiate between personal and non-personal data and open data pools (CEMA, 2000). Open data pools (or data commons) would allow for public-sector-led monitoring of multiple causes and critical yield dynamics, which in turn would facilitate early responses to yield losses due to climate change, mismanagement, or other causes. The successful implementation of such databases, in concert with private-sector data from farmers and businesses, should make a significant contribution to resilient farming systems, innovation, and competition in the service of food security.

## 6. Conclusions

The presented transdisciplinary process targeted the identification of perceived risks and vulnerabilities emerging from unintended side effects of the digital transformation in agriculture. In the course of the transdisciplinary learning process, we identified four major impact areas: 1) effects on agro-ecology, 2) consequences for data rights and market concentrations, 3) changed knowledge requirements and influence on decision-making capabilities, and 4) effects on food security. In addition, we analyzed causal factors and synthesized underlying mechanisms such as the digitalization and technological mechanisms themselves; restructuring of the value chain (new global players and networks); market mechanisms (market concentrations, new dependencies, and optimization parameters); mechanisms of decision-making support; and increasing system complexity and new requirements for knowledge and adaptive capacities. These results not only support but also complement prior empirical (anticipatory) studies from Ireland, Australia and New Zealand (Eastwood et al., 2019; Fleming et al., 2021; Regan, 2019). However, the results presented here go one step further. Instead of looking at individual technologies as separate technological developments, this process took a system perspective and looked at the digital transformation in agriculture as a whole. In addition, it involved a range of stakeholders who not only represented different societal interests and perspectives but also contributed different knowledge. This made it possible, in a joint and mutual learning process, to provide first responses for dealing with the anticipated unintended side effects. In spite of fundamental contrasting perceptions among the actors involved, thus, a set of jointly shared and socially robust orientations (SoROs) were co-developed and discussed for the socially responsible handling of the digital transformation including key requirements. These point to essential directions for future work and research. In accordance with the co-developed SoROs, it needs:

- independent research to monitor and evaluate the agro-ecological risks and benefits of digitalization;
- a participatory co-design of appropriate models for data use and access rights;
- the strengthening of adaptive capacities, knowledge, and “digital literacy” on the part of farmers; and
- the consideration of global data commons databases (for certain data) to allow for meaningful innovation and to avoid critical information asymmetries that may harm food security on a global level.

These jointly formulated SoROs can be seen as the first concrete approaches to action for different groups of actors such as farmers’ associations and scientists as well. In a next step, we seek to further validate and specify the results in a broad consultation process and to underpin them with in-depth research.

Co-developing SoROs in a transdisciplinary process is one way of transforming knowledge from an anticipation process to responsive action. Thus, this paper contributes to the ongoing debate on the successful implementation of RRI principles in digitalization processes, where this has been highlighted as a major challenge. In this context, the transdisciplinary process also initiated a discourse and, thereby, a process of problematization on unintended side effects of the digital transformation. This is seen as an important prerequisite for responsibilization (Rijswijk et al., 2021) and, ultimately, for governance activities to shape the digital transformation in agriculture. Key stakeholders who participated in the presented transdisciplinary process will presumably apply and disseminate the essentials of the SoROS.

The results of the transdisciplinary process have shown that new digital technologies have great potential to contribute to more sustainable and cleaner agricultural production. However, these achievements cannot be taken for granted. An ongoing process of adaptive socio-technical co-development and learning is therefore needed to adjust these new technologies to the demands of the diverse site conditions and complex socio-ecological interactions in agricultural landscapes and to adopt them accordingly, especially also taking into account the often very context-specific societal normative objectives.

## CRediT authorship contribution statement

**Jana Zscheischler:** Conceptualization, Methodology, Investigation, Data curation, Writing – original draft, Writing – review & editing, Facilitation of the transdisciplinary process. **Reiner Brunsch:** Conceptualization, Data curation, Writing – review & editing. **Sebastian Rogga:** Conceptualization, Data curation, Visualization, Writing – review & editing. **Roland W. Scholz:** Conceptualization, Methodology, Investigation, Data curation, Writing – review & editing, Supervision, Initiation of the transdisciplinary process.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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