



Understanding the public attitudinal acceptance of digital farming technologies: a nationwide survey in Germany

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Abstract

The magnitude of public concerns about agricultural innovations has often been underestimated, as past examples, such as pesticides, nanotechnology, and cloning, demonstrate. Indeed, studies have proven that the agricultural sector presents an area of tension and often attracts skepticism concerning new technologies. Digital technologies have become increasingly popular in agriculture. Yet there are almost no investigations on the public acceptance of digitalization in agriculture so far. Our online survey provides initial insights to reduce this knowledge gap. The sample (n = 2012) represents the German population in terms of gender, age (minimum 18 years), education and size of place of residence. Results showed that if the potential of digital farming technologies (DFT) regarding animal welfare and environmental protection was described, respondents reacted positively. Thus, the general attitudes of respondents toward the benefits of DFT were mostly positive. The approval to increasing adoption rates of particular DFT by providing subsidies was also high. Linear regression models showed that the dominant positive influences on respondents' attitudes toward the benefits of DFT were a generally positive attitude toward farming and a strong trust in farmers in Germany. Confronting respondents with pictures showing DFT resulted in many spontaneous negative associations and general criticism of agricultural production. The latter holds true for DFT in animal husbandry in particular. However, as agriculture as a whole is criticized by many groups in Germany, it is unlikely that benefits from digitalization will significantly increase the public acceptance of agriculture as a whole.

Keywords Spontaneous associations · Precision livestock farming · Precision crop farming · Dairy · Robot

Abbreviations

DFT Digital farming technology

Introduction

Public acceptance of digital farming technologies

In recent years, digitalization has found its way into agriculture and is now increasingly used in both animal husbandry and crop production. Digital farming technologies (DFT) include, for example, the application of sensors, automation, and robots in production systems (Banhazi et al. 2012; Shamshiri et al. 2018). Currently, stakeholders in the sector confirm that digitalization may increase public acceptance of agriculture because of its potential regarding animal welfare and more environmentally-friendly production. However, increased agricultural efficiency through digitalization is not necessarily accepted by the public as these technologies may also be perceived as a threat (Driessen and Heutinck 2015; Pfeiffer et al. 2019). In the past, it has been shown that innovative technologies have often been met with little or no acceptance in the public, and in some cases have even had to endure far-reaching criticism as a result (Frewer et al. 1997; Bauer 2002). Indeed, public concerns about the introduction of modern technologies, especially in the food and

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agricultural system, have often been underestimated (Shaw 2002; König et al. 2010; Gupta et al. 2012). Thus, it is essential to analyse the public acceptance of innovations right at the beginning of their developmental process in order to ensure a successful implementation later on (Millar et al. 2002; Verbeke et al. 2007; Gupta et al. 2012).

Although public acceptance of DFT is of paramount importance, little research has been conducted in this area. Often, the economic and environmental impacts of farming systems are analyzed while the social component is neglected. In a recent review of the literature on digitalization in agriculture the authors concluded that the topic has gradually entered social science (Klerkx et al. 2019). Klerkx et al. confirmed that studies published so far have focused on topics such as adoption and adaptation of technologies, effects on farm work as well as ownership, privacy, and ethics in digital agriculture. However, no comprehensive studies have been listed for the research field of public perception of DFT. Nevertheless, the necessity of analyzing possible social resistance in the establishment of new technologies has been acknowledged (Stilgoe et al. 2013; Asveld et al. 2015; Rose and Chilvers 2018). Wathes et al. (2008) emphasized that new farming technologies may have a wider impact not only on farmers and animals, but also on society, which should be evaluated objectively to identify ethical issues. Along this line, Eastwood et al. (2019) pointed out that too much emphasis was placed on the development and adoption of smart farming technologies on farms while socio-ethical implications of society were neglected.

Studies on public acceptance in general provide first impressions of factors, which may also play a putative role in the public acceptance of DFT. Analyzing 292 research papers regarding determinants influencing public acceptance of technologies (e.g., pesticides, nanotechnology, cloning), Gupta et al. (2012) showed that six major determinants accounted for about 60% of all determinants mentioned: perceived risk, trust, perceived benefit, knowledge, individual differences and attitudes. In the literature, intra-personal, inter-personal, but also technology-related characteristics appear to form public acceptance of innovative food technologies (Bearth and Siegrist 2016). More precisely, Bearth and Siegrist's (2016) meta-analysis provided evidence of predictors such as socio-demographics, knowledge of food technology, trust in the regulators of the technologies, perceived naturalness of the food technology as well as risk and benefit perception. Regarding technologies in the food sector, perceived risks and benefits are often characterized as decisive determinants of public acceptance (Ronteltap et al. 2007; Gupta et al. 2012; Bearth and Siegrist 2016). If the public associates too little benefit with a technology, the fundamental need for an innovative technology is called into question (Gaskell 2000). Communicable, perceived benefits that increase the potential for public acceptance of a new

technology can be triggered, for example, by a reduction in the final product price or an increase in product health (Spence and Townsend 2008). At present, there is only superficial knowledge of the publicly perceived risks and benefits of DFT, and even less knowledge of their influence on public acceptance.

Some studies investigated the public acceptance of agriculture and modern farming in general (e.g., Sharp and Tucker 2005; Boogaard et al. 2011a; Kühl et al. 2019), new agrifood technologies such as genetic engineering or nanotechnology (e.g., Frewer 2017), renewable energy innovations (e.g., Devlin 2005; Wüstenhagen et al. 2007; Stiehler 2015), and novel agricultural production methods in and on urban buildings (Specht et al. 2016). In the context of agriculture and modern farming, research on public acceptance has focused on individual aspects of animal husbandry such as animal welfare (e.g., Kendall et al. 2006; Deemer and Lobao 2011). Public concern about animal welfare is mainly associated with modern animal husbandry and, in particular, with increasing farm sizes as shown by studies in North-West Europe and the US (Bennett 1997; Winter et al. 1998; Sharp and Tucker 2005; Boogaard et al. 2011a). A study conducted by Boogaard et al. (2011a) revealed that modern dairy farming is viewed critically by Dutch society as it is associated with a loss of family farms and growing herd sizes, and thus contradicts the desired image of dairy farming. Here, modern dairy farming was considered as a whole, with no focus on specific innovations or technologies. The survey of Boogaard et al. (2011a) provided evidence that public acceptance of modern dairy farming (e.g., farm practices, farm animals) is determined by the following factors: values and convictions, knowledge, relation to agriculture regarding explicit working experience and farm visits, and socio-demographics. This relationship is supported by Sharp and Tucker (2005) who analyzed public opinion about large-scale livestock farming using livestock welfare concern and livestock environmental concern as target variables. Their survey among inhabitants of the US state of Ohio revealed an influence of socio-demographics, physical and social distance from agriculture, agricultural attitudes, and trust in farmers.

Further studies on the public acceptance, without a focus on agriculture, provide additional information on possible influencing factors. In the field of renewable energy, research has been carried out on the public acceptance of new technologies such as biomass plants or wind turbines, revealing an influence of factors such as socio-demographics, knowledge, working experience in the sector, trust in key actors, perceived benefit and costs, and general attitudes (e.g., toward environmental protection) (Devlin 2005; Devine-Wright 2008; Stiehler 2015).

Even technological developments overlapping with other industries such as autonomous driving find

little attention in agricultural literature. While the public acceptance of autonomous driving has already been researched in the automotive industry (e.g., Fraedrich and Lenz 2016), the public acceptance of autonomous machines for agricultural practice have never been studied in-depth. A recent study carried out across the EU provided information on public attitudes toward robotics as one of several technological developments in digital agriculture. In general and regardless of the field of application, a majority (70%) of EU citizens indicated to feel positive about robotics. While the positive attitude toward robotics varied between individual countries, ranging from 54 to 88%, German respondents showed a general positive attitude (69%) toward the application of robotics in agriculture. In the study, the majority of all respondents (88%) agreed with a need for robotics for dangerous work previously carried out by humans (Eurobarometer 2012). However, as the acceptance of autonomous vehicles in general draws a heterogeneous picture, with skepticism certainly being present, the public's attitude toward autonomous agricultural machinery remains to be investigated.

Considering the above cited studies, public acceptance has been studied with regard to various agricultural topics. However, with regard to DFT specifically, the findings were limited to the milking robot so far. As the milking robot is one of the first autonomous machines in dairy farming, it has been the subject of analyses on social aspects of technologies in dairy farming. However, the focus in this respect is mostly on animals and farmers, covering topics such as human-animal-technology interaction or impacts on animal welfare (e.g., Wenzel et al. 2003; Holloway et al. 2014; Driessen and Heutinck 2015), neglecting the overall social perspective. In their study on consumer attitudes toward the use of dairy technologies, Millar et al. (2002) demonstrated social concerns about DFT in terms of the milking robot, as only 39.3% of participants of a UK postal survey rated the milking robot as "ethically acceptable" and only roughly 30% would have welcomed its use in practice. In addition to the questionnaire, a short description of the milking robot was provided to the participants. Apart from demographic and household information as well as awareness of the technology, only little information on further factors possibly influencing the acceptance was included in the study (Millar et al. 2002).

In summary, so far results of the existing literature have shown that agriculture is certainly situated in an area of social tension. However, it is unclear to what extent the public accepts new DFT in different fields of application and whether concerns will potentially lead to future public debates.

Research methods and concept of acceptance

Modern acceptance research comprises a multitude of approaches to a variety of research objects (e.g., consumer products, technologies, political decisions). Many of these objects are judged by people in their roles as users, consumers, or citizens. Accordingly, the literature provides a plethora of characterizations for numerous concepts of acceptance, which differ not only in extent (individual, group attitude), level of observation (specific, general), and detectable effects. The term acceptance itself also has a versatile character. Endruweit (1986) defined the goal of acceptance research as determining the probability of a positive reaction to a certain stimulus. Thus, acceptance can be seen as the result of an interaction process (Hofinger 2001), as the adoption of an object or idea (Dethloff 2004) or as the mere allegorization of an opinion expressed at a certain point in time (Lucke 1995).

It turns out that several studies apply a purely attitude-based understanding of acceptance, as *public attitude* is used as a measure of advocacy or rejection in public (e.g., Devine-Wright 2008; Amin et al. 2011) and attitude-oriented approaches are used to survey opinions on technologies in the population. Schäfer and Keppler (2013) noted that an attitude-oriented understanding of acceptance may also include intention or willingness to act, but not action itself (see Lucke 1995). They considered several studies on acceptance and concluded that the majority that treats acceptance as a comprehensive construct includes not only an attitude component but also an action component (see e.g., Huijts et al. 2012).

Our research approach to determine public acceptance leans on the acceptance process described by Kollmann (2004), who based his studies about the acceptance process of innovative consumer products on three subsequent behavioral phases. He determines the first phase in the acceptance process as the attitude toward a product prior to purchase or use (assessment phase). The second phase in the acceptance process is described as action phase and is characterized by the purchase and adoption of a product. Building on the first two phases, the use phase of the purchased product follows as the third phase and is understood as completion of the acceptance process.

When looking at new technologies that directly benefit separate groups (farmers, animals) and only indirectly affect the respondent personally (e.g., through health benefits and quality of life, improving animal welfare, preservation of the natural environment), it is difficult to determine public acceptance, as is the case with DFT. Therefore, we do not analyze acceptance as a complete construct including a use phase, but follow the approach of attitude-oriented acceptance research and measure the first phase of

Kollmann's acceptance model (attitude); hence the term *attitudinal acceptance*.

The focus in acceptance research was on the cognitive component for a long time, but the relevance of affect in decision making has gradually been recognized. It has been postulated that relying solely on cognitive components is not effective (see Mowrer 1960; Shafir et al. 1993). Initially it was unclear whether attitudes are also directly influenced by non-cognitive factors. Over time, however, studies have increasingly shown that affect can be independent of cognitive structures and thus influences attitudes directly (Onur Bodur et al. 2000). People give affective responses rapidly and automatically, thus representing spontaneous, rather than deliberate, associations. They express an emotional state and reflect a negative or positive stimulus that may be connected to pictures created in the mind. Reliance on such feelings is described as the "affect heuristic" (Collier 1957). People rely on their "affective pool", which contains both positive and negative connotations. Regarding affects, people refer to events in the past that have remained in their memory, including emotional states associated with them (Zajonc 1980; Epstein 1994; Finucane et al. 2000; Slovic et al. 2007; Spence and Townsend 2008). According to Slovic et al. (2007), incorporating affective impressions is easy and efficient, especially when the assessment is complex or knowledge is limited, as is the case with DFT.

Although the majority of studies described above rely on quantitative approaches, methods of acceptance research go far beyond quantitative analyses. As qualitative research approaches can make a valuable contribution to measuring acceptance, they are increasingly being used on agricultural topics to clarify a wide range of questions regarding the acceptance of agriculture. To measure acceptance, pictures and videos have already been used to stimulate spontaneous associations of survey respondents (Harper 2002; Köhl et al. 2019). Media, such as pictures, can evoke "affective resonances" (Shouse 2005) as well as being "repositories of feelings and emotions" (Cvetkovich 2003). Thus, affect and emotions are elicited by the targeted use of media. Suchar (1989) described the revealing of aspects of "social psychology" as one of the reasons for the application of photo-elicitation. Especially in comparison to a purely text-based survey, the benefits of photo-elicitation are the stimulation of latent memory, the awakening of deeper elements of human consciousness and the release of emotional statements, thus eliciting additional information (Collier 1957; Harper 2002; Richard and Lahman 2015). Analysis of elicited emotions, in addition to assessing given statements, serves to capture determinants of attitudes and acceptance such as risk perception (Sjöberg 2007; Gupta et al. 2012).

Research fields

In the current context of agriculture as a field of social tension, questions arise regarding the extent to which a use of modern DFT will be supported by the public as a whole. We conducted a survey among the German public to gather insights into their opinion on the digitalization of farming. To better elucidate the opinion of respondents, we employed a mixed method approach, as recommended by Weary and Keyserlingk (2017). The following research fields (1), (2) and (3) were queried by Likert scales to gain information on the public attitudinal acceptance of DFT (quantitative approach). For research field (4), a qualitative approach was employed including spontaneous associations with pictures showing specific DFT.

- (1) General attitudes of respondents toward the use of DFT and evaluation of the effects of DFT on farmers, consumers, animal husbandry and crop production. Respondents' consent to the use of selected DFT in animal husbandry- and crop production-practice.
- (2) Extent of the respondents' agreement to a provision of a state subsidy to farmers as a means to disseminate DFT in practice.
- (3) Influence of the factors *socio-demographics, connection to agriculture, knowledge of present-day agriculture, trust in farmers, and general attitudes toward farming* on the attitudinal acceptance of DFT.
- (4) Respondents' spontaneous associations with pictures showing specific DFT to gain first insights into concerns and benefits being associated with the technologies.

Materials and methods

Empirical model to measure public attitudinal acceptance of digital farming technologies

We developed a specific model to evaluate the public attitudinal acceptance of various DFT and to detect the relevant factors responsible for shaping these attitudes. An online survey was elaborated to collect first-time empirical data from a representative sample of the German adult population.

According to Kollmann (2004), the attitude toward a product (assessment phase) is composed of awareness, interest, and expectations. Addressing the subordinate indication of consumer expectations and assessment of the use of a new technology, we measured the general attitudes toward the benefits of DFT, the consent to the use of DFT,

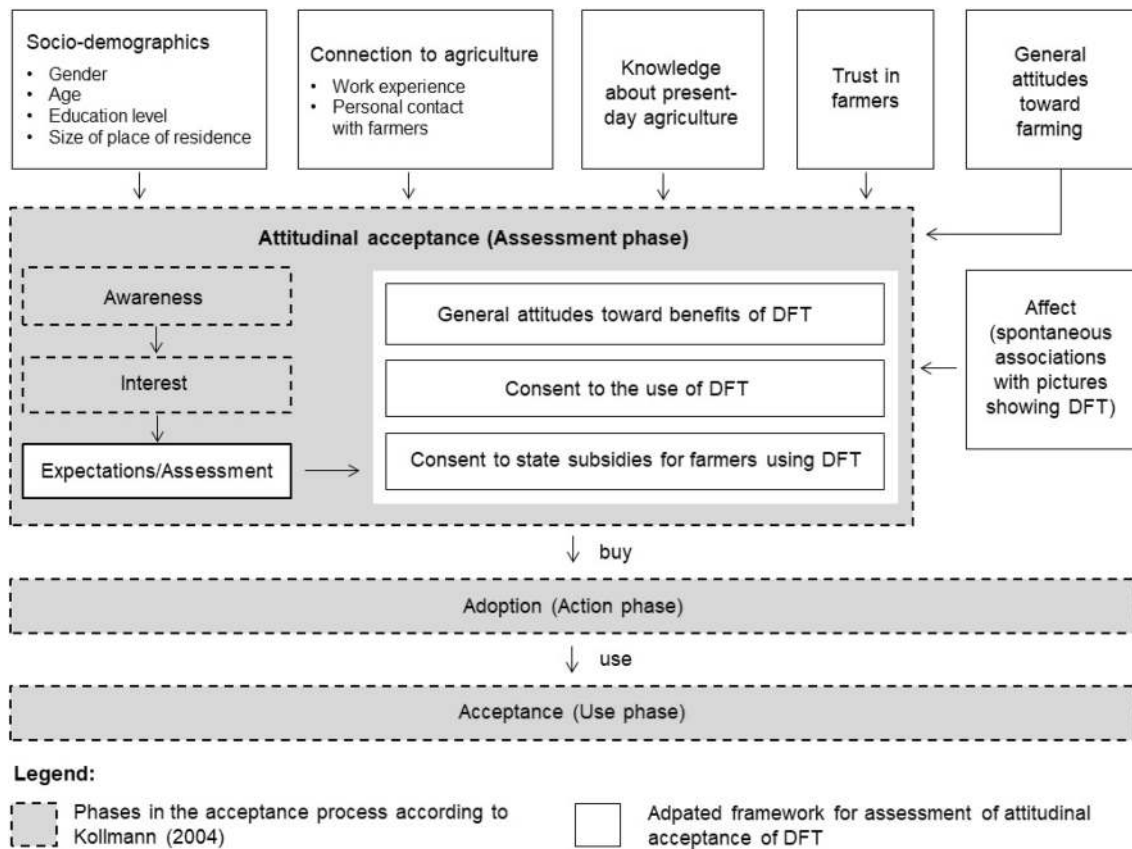


Fig. 1 Framework for measuring acceptance. Adapted from Kollmann (2004). DFT digital farming technology

and the consent to state subsidies for farmers using DFT as target variables of attitudinal acceptance (see Fig. 1). The two other phases in Kollmann’s acceptance model relate to the decision and final use of the new technology. Since in our case the population does not purchase and use the technology itself, but chooses the products resulting from it, an investigation that goes beyond attitudinal acceptance was omitted.

Questionnaire structure

In the first part of the study, information on consumers’ socio-demographics was gathered and Likert scales were applied to assess attitudes toward DFT. Relevant literature on thematically similar acceptance studies was used to compile the influencing factors and scale items included. Based on the review by Gupta et al. (2012), we used the determinants described as the most relevant ones of public acceptance of technologies to gain information about influences on the attitudinal acceptance of DFT. In our model, individual differences were covered as the factors *socio-demographics* and *connection to agricultural sector*. Knowledge, trust and attitudes are further determinants of public acceptance of technologies integrated into the model (see Gupta et al. 2012).

We queried them as the factors *knowledge of present-day agriculture*, *trust in farmers*, and *general attitudes toward farming*. To measure both latent predictors and target variables for the objectives on the analysis, Likert scales were used as essential components. To prevent skewed results due to certain answering patterns, the order of the items in each of the surveyed scales was randomly distributed for each respondent. In a further part of the questionnaire, photo-elicitation was used to gather spontaneous associations with pictures showing different DFT. Scale items from the first survey part do not allow us to identify reasons that are seen by the public as promoting or inhibiting attitudinal acceptance of DFT. Therefore, we applied photo-elicitation as a second methodological approach to elicit affect-based thoughts from the respondents.

Socio-demographics and quota control

Based on recent studies, socio-demographics were expected to potentially play a role in the attitudinal acceptance of DFT (Haartsen et al. 2003; Sharp and Tucker 2005; María 2006; Devine-Wright 2008; Boogaard et al. 2011a). Therefore, we evaluated the socio-demographic distribution of the survey sample by assessing four variables: age, gender, education

and size of place of residence. Regarding the size of place of residence, we included three categories, due to the hypothesis of different rural–urban attitudes toward agriculture and environmental issues (Van Liere and Dunlap 1980; Freudenburg 1991; Sharp and Tucker 2005; Boogaard et al. 2011a). The categories of the variables were classified on the basis of official population statistics and literature-based considerations. This resulted in the classification of the variables of age (five categories, minimum 18 years), education (five categories), size of place of residence (three categories), and gender (two categories).

Connection to agricultural sector

In addition to socio-demographics, contact with agriculture or farmers can have an impact on the respondents' acceptance of agriculture and of innovative technologies specifically (Devlin 2005; Sharp and Tucker 2005; Delezie et al. 2006; Devine-Wright 2008; Boogaard et al. 2011a). Personal contact with farmers in the social environment, exchange about agricultural topics, or professional experience in the areas of agribusiness and food supply allows people to gain expertise and consolidate points of view. Therefore, we included scales on work experience in the agricultural sector and on personal contact with a farmer as independent variables. Within the scale of personal contact with a farmer, we differentiated whether or not conversations also covered agricultural topics.

Predictors from Likert scales

General attitudes toward the subject context may transpire to be an acceptance-relevant factor or a basic prerequisite for acceptance (Lucke 1995; Grunert et al. 2003; Kollmann 2004). In our study, the scale *general attitudes toward farming* was rated via five items. Since public acceptance may be determined by inherent characteristics of technologies as well as by their impact on humans, nature and animals, the items refer to relevant topics confirmed in previous studies to be decisive regarding public acceptance. Since these aspects were rated by the majority of respondents in the study by Boogaard et al. (2011a) as desired image of agriculture, the two items “Preservation of the environment for future generations” and “Welfare of farm animals is important” were included in the scale of our survey. Additionally, the item “I have a fundamentally positive attitude toward agriculture in Germany” was integrated, following previous results of scale measurement of consumer attitudes toward livestock welfare and environmental concerns (Sharp and Tucker 2005) and toward the use of renewable energies in the direct environment (Stiehler 2015). As the support of small farming structures was positively associated with livestock welfare concerns and environmental concerns in the study by Boogaard

et al. (2011a), we included the item “Family farming structures seem valuable and should be preserved” as an item on the scale. As a further item, “Farmers should get more free time” was added. The scale was supplemented by three additional items to quality-check participants' response behavior after completion and the plausibility of the answers. These additional items were not included in the analysis.

Since knowledge can be a decisive determinant of the public acceptance of a new food technology (Bearth and Siegrist 2016) it was included in our model. According to Te Velde et al. (2002), the construction of perceptions in individuals is influenced by factors such as experience- and impression-based knowledge. Along this line, a survey by Stiehler (2015) found supportive empirical evidence, revealing that public acceptance of biomass cogeneration heat (and power) plants significantly depended on the degree of information in this field. However, a review on public acceptance of renewable energy technologies by Devine-Wright (2008) has suggested that a higher level of knowledge is not necessarily correlated with higher public acceptance. Whether there is a connection between the level of knowledge of present-day agriculture and the public acceptance of DFT is, to date, unclear. Therefore, the analysis of the relationship between knowledge of agricultural processes and public attitudinal acceptance of DFT can provide initial indications as to whether providing information on agriculture can influence public attitudinal acceptance of DFT. In our study, cognitive knowledge, in terms of having knowledge of a fact, was assessed by the scale *knowledge of present-day agriculture*. Survey respondents were asked to self-assess their level of knowledge on animal husbandry, crop production and modern agricultural equipment.

Besides the *general attitudes toward farming* and *knowledge of present-day agriculture* scales, the scale *trust in farmers* was included in the model. Studies on the acceptance of new technologies often focus on inherent characteristics of technologies, although several studies provide solid empirical evidence that trust in the user of a new technology is also a crucial influencing factor in public acceptance (Dunlap et al. 1993; Slovic 1993; Cvetkovich and Lofstedt 1999; Eiser et al. 2002; Roosen et al. 2015; Stiehler 2015; Bearth and Siegrist 2016). Siegrist et al. (2000) explicitly described trust as “social trust”, i.e. relying on people who are in charge of handling a technology, and emphasized that the group of people being trusted is usually not known personally. Especially when one's own knowledge and interest in a technology is limited, trust in people using the technology appears all the more relevant (Siegrist et al. 2000; Bearth and Siegrist 2016). Wüstenhagen et al. (2007) illustrated public acceptance of renewable energy innovation as a triangle, consisting of the three dimensions of socio-political, market, and community acceptance, of which the latter represents a central component of trust. In addition,

Sharp and Tucker (2005) demonstrated that elevated trust in farmers is associated with less concern about livestock welfare and environmental aspects of large-scale livestock and poultry operations. To take social trust into account, we surveyed the items “German farmers pay great attention to the welfare of their animals” and “German farmers protect our environment”.

Target variables from Likert scales

Since digitalization in agriculture is per se an abstract topic for many of the respondents, we introduced them to DFT by means of some general information and the presentation of examples of DFT. Four individual DFT were illustrated and briefly explained in the questionnaire as specific examples: spot spraying (selective application of pesticides in crop production), digital hoeing (alternative chemical weed control), near-infrared spectroscopy (NIR) sensor technology (measuring nutrient content in manure), and sensors for animal husbandry (early detection of problems and diseases in animals in livestock farming). Respondents gave their approval or disapproval on five-point Likert scales. The scale *general attitudes toward the benefits of DFT* was used to assess public acceptance of DFT on a general level. The rating of DFT was conducted not only at a general level, but also at a technology-specific level. With regard to each of the four specific DFT mentioned, the respondents stated their level of *consent to the use of specific DFT* and their level of *consent to state subsidization for farmers using DFT* as target variables.

Spontaneous associations with digital farming technologies

In the second part of the online survey, respondents were asked for voluntary spontaneous associations with pictures showing DFT. For animal husbandry, pictures of a cow during the milking process in a milking robot and of cows in a barn being fed by a feeding robot were selected.^{1,2} For crop production, pictures of an autonomous tractor and of a swarm of small robots, both during the sowing process on the field, were shown.^{3,4} We deliberately chose pictures of these four technologies from the internet to obtain feedback

on widespread media-based pictures of DFT. For each of the two digital technologies in dairy farming and crop production, up to three spontaneous associations could be stated. Survey participants were not given any additional information about the respective pictures. The spontaneous associations helped to identify further reasons for attitudinal acceptance of DFT (or a lack thereof).

While the rating of given statements with Likert scales in the first part of the questionnaire served to provide a cognitive evaluation of DFT by the respondents, the affect- and thus emotion-based approach provided another dimension of determining attitudinal acceptance, as cognitive and emotional responses do not necessarily align. As emotions serve to capture risk perception, the spontaneous associations were supposed to obtain initial indications of the risks and benefits that respondents associate with some examples of DFT. This should pave the way for further analyses of perceived benefits and risks in order to optimize communication with the public on the subject of DFT.

Data collection: nationwide online-survey

The questionnaire was handed to a professional field service provider with an extensive nationwide online consumer panel, thus facilitating sample determination (German residents aged at least 18 and with internet access) and enabling a pre-set quota control of the sample for representativeness regarding selected socio-demographics. For representative evaluation of the German adult population in terms of age, gender, education level, and size of place of residence, statistical data from the “b4p- Best for planning 2017” dataset were used to pre-select the quota in this survey. b4p is a long-term market media study program in Germany that has been analyzing media use and consumer behavior (random sample of more than 30,000 participants older than 13 years) since 2013. This enables target group-specific distribution quotas via queries at associated counting services.

In 2018, 90% of the German population used the internet, with the proportion of internet users being lowest among the older generations (Federal Statistical Office Germany (Destatis) 2018a). However, as our sample is representative in terms of age, we can ensure that age groups are covered by the respective shares of the entire sample (see Table 1). Collecting data online enabled us to obtain a large and geographically distributed sample within a short time, thus saving time and costs (see also Stanton 1998; Ilieva et al. 2002; Lefever et al. 2007). Nevertheless, it can be critically noted that our survey on digital technology only addressed people who are familiar with the internet.

Furthermore, choosing an online survey as data collection method enabled an adaptive course of the survey, depending on the information provided by the interviewees, and therefore an effective and user-friendly procedure. The integration

¹ <https://www.schweizerbauer.ch/landtechnik/firmen--personen/20000-melkroboter-von-lELY-in-betrieb-19341.html> (accessed on June 15, 2018).

² <https://melktechnik-center.com/Fuetterungstechnik/FMR-Roboter/> (accessed on 15 June, 2018).

³ <https://www.caseih.com/emea/de-at/News/Pages/2016-08-30-Case-IH-stellt-auf-der-Farm-Progress-Show-neues-Traktorkonzept-vor.aspx> (accessed on June 15, 2018).

⁴ <https://www.fendt.com/int/fendt-mars> (accessed on June 15, 2018).

Table 1 Socio-demographic distribution of survey sample (n=2012)

| | Variable | Category | Absolute frequency | Relative frequency (%) | |
|---|---|---|--------------------|------------------------|------|
| Socio-demographic characteristics | Gender ^a | Female | 1011 | 50.2 | |
| | | Male | 1001 | 49.8 | |
| | Age ^a | 18–29 years old | 340 | 16.9 | |
| | | 30–39 years old | 364 | 18.1 | |
| | | 40–49 years old | 395 | 19.6 | |
| | | 50–59 years old | 459 | 22.8 | |
| | | 60 years and older | 454 | 22.6 | |
| | Size of place of residence ^a | Less than 5000 inhabitants | 284 | 14.1 | |
| | | 5000 to 99,999 inhabitants | 1075 | 53.4 | |
| | | 100,000 and more inhabitants | 653 | 32.5 | |
| | Education level ^a | No general school-leaving qualification (yet) or basic secondary school ^b without vocational qualification | | 94 | 4.7 |
| | | Basic secondary school ^b with vocational qualification | | 487 | 24.2 |
| | | Higher secondary school-leaving qualification ^c or upper secondary school ^d | | 686 | 34.1 |
| University entrance qualification ^d without university degree | | 327 | 16.3 | | |
| University degree (university, college, technical college, academy, poly-technic) | | 418 | 20.8 | | |
| Connection to agricultural sector | Work experience | Work experience in agricultural sector | 165 | 8.2 | |
| | | No work experience in agricultural sector | 1847 | 91.8 | |
| | Personal contact with farmers | Yes, with conversations about agricultural topics | 387 | 19.2 | |
| | | Yes, without conversations about agricultural topics | 285 | 14.2 | |
| | | No | 1340 | 66.6 | |

^aRepresentative distribution of the German population according to b4p dataset 2017 (German residents over 18 with permanent access to the internet)

^bBasic secondary school (*Mittelschule*), leading to basic school-leaving qualification (*Qualifizierender Abschluss*)

^cHigher secondary school (*Realschule*), leading to higher school-leaving qualification (*Mittlere Reife*)

^dUpper secondary school (*Gymnasium*), leading to University entrance qualification (*Abitur*)

of additional information (short information on the purpose and function of specific DFT) and visual material (pictures showing selected DFT) into the online questionnaire supported the conduct of the survey and provided more clarity to the respondents for better responsiveness. The online questionnaire was pre-tested by a subsample of the online panel of 10% of the desired total sample size concerning comprehensibility and technical procedure of the survey. Subsequently, the main survey was carried out from July 13 to 23, 2018. In total, more than 4,000 online interviews were initiated, with 2215 completely answered data sets remaining due to lack of target group affiliation or quota fulfilment. After final quality control, 2012 data sets could be used for the analysis.

Analyzing methods

In order to use the individual scales for further calculations, homogeneity and internal consistency of the overall constructs (scales) and reliability of the items were checked by Cronbachs α ($C\alpha$).⁵ Using the Spearman-Brown test, the contribution of each item to scale reliability could be determined to obtain the overall scale quality and, if necessary,

⁵ While $C\alpha$ test values above 0.7 are assumed to be acceptable (“acceptable” ≥ 0.7 , “good” ≥ 0.8 , “excellent” ≥ 0.9), measures below this limit cast doubt on the homogeneity of the scale (“questionable” < 0.7 , “poor” < 0.6 , “unacceptable” < 0.5) (see Field 2017).

to decide whether individual items should be excluded from a scale (Field 2017).

Reliability analyses can be equated with a confirmatory one-dimensional factor analysis, allowing for the assignment of an individual, metric-scale value (factor value) to each data set. The metric values for each of the scales were applied in the subsequent multivariate regression model to identify their impacts on respondents' attitudes concerning DFT, consent to the use of specific DFT, and consent to a state subsidy for DFT. Further predictor co-variables (socio-demographics, respondents' connection to agricultural sector) were dummy-coded and added to the three linear regression models.

Regarding the spontaneous associations affected by the respective pictures of DFT, statements not suitable for evaluation (e.g., "I have no idea", "I don't know") were removed from the data set. After that step, depending on the specific technology, 3982 (swarm robots), 4035 (feeding robot), 4397 (autonomous tractor), and 4649 (milking robot) associations were included for further analysis. Categories including similar terms and expressions were formed allowing a categorization of associations. Nine categories were applicable to all shown technologies (e.g., *Future and Progress*). Besides, the formation of five animal- (e.g., *Animal Cruelty*) and seven crop-specific (e.g., *Concerns for Environmental Protection*) categories was necessary. For illustrating the result of the analysis, the ten categories most frequently associated with each of the four pictures, respectively, were compiled. Within each category, the connotation of the individual associations was evaluated as negative ("−"), neutral ("0") or positive ("+"). If associations with different connotations were found in a category, multiple connotations were assigned. By assigning connotations, our approach resembles that of Kühn et al. (2019), who categorized associations with pictures of different husbandry systems for dairy cattle and classified them as negative or positive.

Results

Socio-demographic distribution and connection to agriculture of survey sample

The distribution of the survey sample ($n = 2012$) represents the German population with regard to the socio-demographic characteristics of gender, age (minimum 18 years), size of place of residence, and level of education (see Table 1). With regard to their connection to agriculture, 8.2% of respondents stated that they have some work experience in the agricultural sector, while 91.8% have none. 19.2% of respondents know a farmer and discuss agricultural topics with him or her, while 14.2% of respondents know a

farmer with whom they do not talk about agricultural topics, however (Table 1).

Descriptive analysis of response scales

The response scales concerning general attitudes toward farming, knowledge of present-day agriculture as well as trust in farmers were used as predictors for the subsequent multivariate evaluation (independent variables). The scales concerning general attitudes toward the benefits of DFT (D1), consent to the use of specific DFT (D2), and consent to a state subsidy for farmers using DFT (D3) represent the dependent variables. The results of the individual items of the scales are expressed as mean values and standard deviations (Table 2). The responses range between the scale poles of "1 = I fully agree" and "5 = I fully disagree", or "1 = very high", and "5 = very low" for the scale of knowledge of present-day agriculture. The literature-based selection of the items provided "acceptable" to "excellent" quality criteria of the composed scales.

General attitudes toward farming, knowledge, and trust in farmers

The general attitudes toward farming-scale revealed that values linked to agriculture play a relevant role. The preservation of the environment for future generations ($\mu = 1.55$), family farming structures ($\mu = 1.64$), and welfare of farm animals ($\mu = 1.65$) are valued most highly by respondents. On average, respondents indicated that they have a fundamentally positive attitude toward agriculture in Germany ($\mu = 2.06$) and that farmers should get more free time ($\mu = 2.11$). Respondents rated their knowledge of present-day agriculture as mediocre to rather low. In particular, the self-assessment covered production methods in animal husbandry processes ($\mu = 3.33$), crop production ($\mu = 3.53$), and the latest machinery and equipment used in agriculture ($\mu = 3.57$). For all three items of this scale, a substantial proportion of respondents indicated to have very good or good knowledge of present-day agriculture (13.6%, 20.3%, and 12.6%, respectively). Considering that 8.2% of the respondents claimed to have work experience in the agricultural sector, these proportions are high. It is interesting to note that especially those respondents who stated that they have already personally talked to farmers about agricultural issues also claimed a significantly higher level of knowledge of present-day agriculture (T value 20.67; $p = 0.000$) compared to those who have no contact with acquaintances in this sector. This also applies to those respondents who already had their own experiences in the agricultural sector, as opposed to those who have never been in contact with agriculture (T value 12.59, $p = 0.000$).

Table 2 Scales for independent and dependent (D) variables (n=2012)

| Scales | Items | Mean (μ^b) | SD |
|---|---|------------------|------|
| <i>Scale reliability^a</i> | | | |
| General attitudes toward farming $C\alpha=0.72$ | Preservation of the environment for future generations | 1.55 | 0.72 |
| | Welfare of farm animals is important; this influences my actions | 1.65 | 0.74 |
| | Family farming structures seem valuable and should be preserved | 1.64 | 0.74 |
| | I have a fundamentally positive attitude toward agriculture in Germany | 2.06 | 0.83 |
| | Farmers should get more free time | 2.11 | 0.78 |
| Knowledge of present-day agriculture $C\alpha=0.90$ | Knowledge of animal husbandry processes | 3.33 | 1.03 |
| | Knowledge of production methods in crop production | 3.53 | 0.99 |
| | Knowledge of the latest machinery and equipment used in agriculture | 3.57 | 0.99 |
| Trust in farmers $C\alpha=0.80$ | German farmers pay great attention to the welfare of their animals | 2.73 | 0.90 |
| | German farmers protect our environment | 2.77 | 0.89 |
| General attitudes toward the benefits of DFT (D1) $C\alpha=0.75$ | Bring farmers and consumers closer together | 2.80 | 0.92 |
| | Enable a more environmentally-friendly production | 2.31 | 0.82 |
| | Lead to the alienation of the farmer from his soil and animals ⁽⁻⁾ | 2.91 | 1.01 |
| | Improves the quality of life of the farming family | 2.10 | 0.76 |
| | Improves animal welfare and animal health | 2.39 | 0.87 |
| Consent to the use of specific DFT (D2) $C\alpha=0.76$ | Digital hoeing technology | 1.82 | 0.88 |
| | Sensors for livestock farming | 1.92 | 0.88 |
| | NIR sensors for organic fertilization | 1.96 | 0.89 |
| | On-field spot spraying | 2.22 | 1.00 |
| Consent to state subsidization for farmers using DFT (D3) $C\alpha=0.85$ | State subsidization of digital hoeing technology | 2.09 | 1.02 |
| | State subsidization of sensors for livestock farming | 2.16 | 1.03 |
| | State subsidization of NIR sensors for organic fertilization | 2.28 | 1.04 |
| | State subsidization of spot spraying | 2.36 | 1.07 |

DFT digital farming technologies

^aCronbach's α ($C\alpha$) of full-item scale

^b5-point scale: minimum 1=I fully agree/very high; 3=undecided/mediocre; maximum 5=I fully disagree/very low

⁽⁻⁾Original question with negative polarization; $C\alpha$ and mean refer to *ex-post* reversion of item

As a third scale, trust in farmers in Germany was surveyed, which, in contrast to the general attitudes, dealt directly with information on the applied practice of farmers. The results revealed that trust in farmers was rated less positive than the general attitudes toward farming indicated. The agreement that German farmers pay great attention to the welfare of their animals ($\mu=2.73$) and protect our environment ($\mu=2.77$) in their practice was modest. For the two items, a high proportion of undecided respondents (44.2%, and 45.4%, respectively) emerged.

Attitudes toward the benefits of digital farming technologies (D1, D2, D3)

Regarding the general attitudes toward the benefits of DFT (D1), respondents primarily saw an improvement in the quality of life of the farming family through relieving the

farmer ($\mu=2.10$). More environmentally-friendly production ($\mu=2.31$) and improvement of animal welfare and animal health ($\mu=2.39$) were seen as further areas of potential benefits from DFT. The respondents' agreement that DFT bring consumers and farmers closer together was only moderate ($\mu=2.80$). Likewise, a high share of undecided respondents (23.0% to 44.3%) was found for all items on this scale.

The overall consent to the use of sensors for livestock farming, digital hoeing technology, NIR sensors for organic fertilization, and spot spraying (D2) was very high. The mean values for the agreement to their use ranged from $\mu=1.82$ to $\mu=2.22$, with 63.0% to 78.3% of the respondents fully agreeing or agreeing. The consent to the use of spot spraying, however, was markedly lower than that of the other three DFT. Not only was the consent to the use of the DFT in practice high, but also the consent to a state subsidy for farmers using DFT (D3). Here, the averages ranged from

Table 3 Determinants for peoples' attitudes concerning digital farming technologies (n=2012)

| Independent variables ^b | Dependent variables (standardized coefficients) | | |
|---|--|--|--|
| | <i>Model D1</i> General attitudes toward benefits of digital farming technologies | <i>Model D2</i> Consent to the use of specific digital farming technologies | <i>Model D3</i> Consent to state subsidies for farmers using digital farming technologies |
| Constant | 0.045 | 0.138 | - 0.028 |
| Scales variables (metric scaled) | | | |
| General attitudes toward farming | 0.183*** | 0.298*** | 0.308*** |
| Knowledge of present-day agriculture | 0.116*** | 0.044 ^a | 0.030 |
| Trust in farmers | 0.385*** | 0.097*** | 0.237*** |
| Socio-demographics (dummy-coded, standardized) | | | |
| Gender (1 = male) | 0.096* | 0.177*** | - 0.076 ^a |
| Age (1 < 40 years) | - 0.011 | - 0.018 | 0.154*** |
| Education level (1 = university entrance qualification or higher) | 0.063 | 0.205*** | - 0.061 |
| Size of place of residence (1 ≤ 5000) | - 0.055 | - 0.108 ^a | - 0.080 |
| Connection to agricultural sector (dummy-coded, standardized) | | | |
| Work experience in agricultural sector (1 = yes) | - 0.201** | - 0.179* | - 0.114 |
| Personal contact with farmers & discussion about agricultural topics (1 = yes) | 0.006 | 0.029 | - 0.001 |
| R | 0.497 | 0.363 | 0.443 |
| R ² -adj | 0.244 | 0.128 | 0.193 |

***p < 0.001, **p < 0.01, *p < 0.05

^ap < 0.1

^bTesting on multicollinearity shows independence between predictors

$\mu = 2.09$ to $\mu = 2.36$, with 59.5% to 66.7% of the respondents fully agreeing or agreeing, depending on the technology. Again, spot spraying experienced the lowest approval and digital hoeing technology the highest. The statistics showed significantly higher consent to state subsidization of digital hoeing technology and sensors for livestock farming than to NIR sensors and spot spraying.

Determinants for peoples' attitudes concerning digital farming technologies

The linear regression models revealed influence of the independent variables (socio-demographics, connection to agricultural sector, general attitudes toward farming, knowledge of present-day agriculture, trust in farmers) on the dependent variables (digitalization in agriculture models D1, D2, and D3) (Table 3). The main influences on respondents' attitudes toward the benefits of digitalization in agriculture appeared to be general attitudes toward farming as well as trust in farmers. With more positive general attitudes toward

farming, the respondents' general attitudes toward the benefits of DFT (D1) were more positive, and the consent to the use of specific DFT (D2) and to state subsidy for farmers using DFT (D3) was increased. This positive influence on D1, D2, and D3 applied equally to the trust in farmers-scale. It turned out that there were further independent variables influencing the attitudinal acceptance of DFT, but their influence was comparatively low. Respondents who claimed to have better knowledge of present-day agriculture had significantly more positive general attitudes toward the benefits of DFT (D1). There was evidence of a statistically significant influence of gender on the agreement to DFT (D1 and D2). Men had slightly more positive general attitudes toward the benefits of DFT (D1), and their consent to the use of specific DFT (D2) was slightly increased compared to women. In terms of age, it appeared that consent to state subsidy for farmers using DFT (D3) was higher among younger respondents (age classes under 40 years). With higher education (university degree and university entrance qualification without university degree), the consent to the use of specific

Table 4 Partial correlations (Pearson correlation coefficient) between dependent variables

| | D1 | D2 | D3 |
|----|---------|---------|---------|
| D1 | 1 | 0.478** | 0.457** |
| D2 | 0.478** | 1 | 0.602** |
| D3 | 0.457** | 0.602** | 1 |

D1 General attitudes toward the benefits of digital farming technologies; D2 Consent to the use of specific digital farming technologies; D3 Consent to state subsidy for farmers using digital farming technologies

**Correlation at the level of 0.01 (2-sided) significant

DFT (D2) was significantly higher. For the size of place of residence, no significant effect on the attitudes toward digitalization in agriculture could be shown. Respondents claiming to have worked in the agricultural sector had more negative general attitudes toward DFT (D1) and showed less consent to the use of specific DFT (D2). However, the results did not reveal any impact of work experience on the general consent to a state subsidy for farmers using DFT. The three models that address digitalization in agriculture do not show a statistically significant correlation with personal contact with farmers (with and without conversations on agricultural topics).

In addition to the regression model results, partial correlations among the three dependent study variables provide information about their coherences (Table 4). A highly significant positive correlation was found between the consent to the use of the four selected DFT (D2) and the consent to state subsidies of their use in agricultural practice (D3). They are closely linked due to the respective questions being placed consecutively for each technology in the survey. A significant correlation, however, could also be found between these two variables and D1 (general attitudes toward the benefits of DFT), confirming the reliability of the results and the successful choice of measurement methods.

Spontaneous associations with pictures showing digital farming technologies

The ten most frequent aggregate categories of spontaneous associations with the pictures showing specific DFT in crop production and dairy farming are shown in Table 5. Categories that could be formed with all four pictures are *Future and Progress*; *Efficiency and Reduced Workload*; *Technology*; *Digitalization, Autonomy and Automation*; *Industrial agriculture/Size dimension*; *Costs of Technology*; *Farmer*; *Terms of Agreement* and *Terms of Rejection*. Animal-specific categories included *Dairy Farming/Milking*; *Cow*; *Hygiene*; *Animal Cruelty*; *Agriculture*. Crop-specific categories included *Field Cultivation*; *Nature and Plants*;

Environmental Protection; *Concerns for Environmental Protection*; *Animal Protection*; *Safety*; *Human Health*.

The positively connoted category *Future and Progress* appeared for each picture, as respondents assigned attributes such as “futuristic” or “innovative” to each of the presented technologies. Another frequent category was increased *Efficiency and Reduced Workload* for the farmer by means of DFT. In this regard, a high number of respondents stated terms such as “effective”, “fast”, and even “higher precision” of agriculture (for example, in the distribution of feed in the barn). However, as “loss of jobs” was also mentioned several times in this category, the overall rating is mainly positive, but also partially negative. Neutral categories such as *Digitalization, Autonomy and Automation*; *Dairy Farming*; and *Field Cultivation* played a crucial role in the associations with all four pictures. We merged terms such as “machine” and “high-tech” into the neutral category *Technology*, which consistently polled a large proportion of the aforementioned spontaneous associations in all four pictures.

In general, we saw that the most commonly mentioned categories for the animal-related technologies were more negative than those for the crop production technologies. This was especially true for the picture of the milking robot, for which three negative categories were among the five most common. Negative terms with regard to the issue of *Animal Cruelty* such as “animal suffering”, “tight”, “poor cow”, “not animal-appropriate”, and “imprisoned” were associated most frequently with the picture of the milking robot. The issue of *Animal Cruelty* was also mentioned in the context of the feeding robot, but at a lower frequency.

The aspect of *Industrial Agriculture* played a relevant role in the case of the two animal husbandry technologies. Respondents were worried, for example, about “exploitation of the animals”, “alienation”, “factory farming” and “animal as an object” (negative). The picture of the autonomous tractor also led survey participants to think of *Industrial Agriculture*, but at a lower frequency than the dairy farming technologies. In this case, terms such as “impersonal” were noted, but also “mass production”, “large-scale farmers”, and “monster”. Often, however, only the *Size Dimension* was described with terms such as “big” or “large area”, which is why we included this aspect in the category *Industrial Agriculture*. For the picture of the autonomous tractor, this resulted in a combination of neutral and negative associations. Swarm robotics was also associated with words such as “mass production” and “industrial” (negative), but with regards to the *Size Dimension*, it was described as “small”, “toy”, and “cute” (positive). For the picture of the autonomous tractor, many respondents expressed *Concerns for Environmental Protection* (negative), using words like “environmental pollution”, “soil compaction”, “chemistry”, “poison”, and “monoculture”. In relation to the picture of the swarm robots, this category also applied, but only a few

Table 5 Frequently mentioned categories in spontaneous associations with four pictures of digital farming technologies

| Picture 1 Autonomous tractor sowing in the field Total number of mentions suitable for evaluation: 4397 | | | | Picture 2 Swarm robots sowing in the field Total number of mentions suitable for evaluation: 3982 | | | |
|--|---|----------|-------------|--|---|----------|-------------|
| Rank | Aggregate categories | Mentions | Connotation | Rank | Aggregate categories | Mentions | Connotation |
| 1 | Future and Progress | 737 | + | 1 | Digitalization, Autonomy and Automation | 667 | 0 |
| 2 | Efficiency and Reduced Workload | 635 | +/(-) | 2 | Efficiency and Reduced Workload | 643 | +/(-) |
| 3 | Digitalization, Autonomy and Automation | 605 | 0 | 3 | Future and Progress | 591 | + |
| 4 | Field cultivation | 493 | 0 | 4 | Field Cultivation | 357 | 0 |
| 5 | Technology | 452 | 0 | 5 | Industrial Agriculture/Size Dimension | 333 | -/0/+ |
| 6 | Terms of rejection (e.g., “creepy”) | 303 | - | 6 | Technology | 284 | 0 |
| 7 | Terms of agreement (e.g., “good”) | 235 | + | 7 | Terms of Rejection (e.g., “creepy”) | 275 | - |
| 8 | Concerns for environmental protection | 173 | - | 8 | Terms of Agreement (e.g., “good”) | 267 | + |
| 9 | Industrial agriculture/size dimension | 170 | -/0 | 9 | Costs of Technology | 142 | -/(0)/(+) |
| 10 | Nature and plants | 156 | 0 | 10 | Environmental Protection | 76 | + |
| Picture 3 Cow-feeding robot during feed provision in the barn Total number of mentions suitable for evaluation: 4035 | | | | Picture 4 Cow in milking robot during milking process Total number of mentions suitable for evaluation: 4649 | | | |
| Rank | Aggregate categories | Mentions | Connotation | Rank | Aggregate categories | Mentions | Connotation |
| 1 | Efficiency and Reduced Workload | 572 | +/(-) | 1 | Animal Cruelty | 754 | - |
| 2 | Digitalization, Autonomy and Automation | 478 | 0 | 2 | Dairy Farming/Milking | 687 | 0 |
| 3 | Dairy farming/feeding | 475 | 0 | 3 | Terms of Rejection (e.g., “awful”) | 546 | - |
| 4 | Industrial agriculture | 380 | - | 4 | Technology | 470 | 0 |
| 5 | Animal cruelty | 370 | - | 5 | Industrial Agriculture | 427 | - |
| 6 | Future and Progress | 360 | + | 6 | Digitalization, Autonomy and Automation | 385 | 0 |
| 7 | Terms of rejection (e.g., “awful”) | 317 | - | 7 | Future and Progress | 359 | + |
| 8 | Terms of agreement (e.g., “useful”) | 255 | + | 8 | Efficiency and Reduced Workload | 307 | +/(-) |
| 9 | Hygiene | 233 | 0 | 9 | Hygiene | 250 | 0 |
| 10 | Technology | 213 | 0 | 10 | Cow | 177 | 0 |

Ranking of the ten most frequent categories for each of the shown pictures
 Assignments of connotation: “+” = positive; “0” = neutral; “-” = negative

terms could be assigned to it. For the pictures of the milking and feeding robots, we assigned a similar number of terms to the category *Hygiene*, which was mainly composed of words like “hygiene”, “clean”, and “sterile” and rated as neutral. Strikingly, many of the mentioned spontaneous associations did not explicitly target the DFT depicted, but rather criticized agricultural production processes per se. For example, associations such as “factory farming” and “locked up” call the animal husbandry system in general into question. Likewise, terms such as “monoculture”, “environmental

pollution”, and “pesticide” are a criticism of agronomic practices in agriculture, with no specific reference to the DFT depicted.

Discussion

Classification of results

The connection to the agricultural sector and general attitudes toward agriculture

With regard to the connection to agriculture, the sample showed a high proportion of respondents with work experience in the agricultural sector (8.2%) compared to the current share of employed persons in agriculture of about 1.1% in Germany (Federal Statistical Office Germany (Destatis) 2018b). This may be explained, on the one hand, by the fact that some of the respondents' work experience in the agricultural sector lies in the past. On the other hand, the question asked for work experience in the agriculture sector or a related field, which also includes the upstream and downstream sectors (such as food retailing).

The mediocre to rather low knowledge of present-day agriculture in Germany can be explained by increasingly fewer points of contact between farmers and the public (Weber et al. 1995; Holloway 2004). The higher proportion of people who claimed to have good or very good knowledge of agricultural production compared to those who have work experience in agriculture may be attributed to overconfidence (Moore and Healy 2008). The spontaneous associations confirmed a partially low level of knowledge of present-day agricultural production of the German public (see also Simons et al. 2019) as, for example, the milking robot, was often not recognized as such.

In general, the level of trust in farmers in Germany was only moderate. The agreement that farmers contribute to the protection of the environment and pay close attention to the welfare of their animals behaved similarly moderately in other studies conducted in Germany (Helmle 2010), but also in the Netherlands (Boogaard et al. 2011a) and the US-State of Ohio (Sharp and Tucker 2005). The fact that respondents rated the items of trust in German farmers better than those reflecting their knowledge of present-day agriculture showed that a comprehensive knowledge of current agricultural production methods among the public is not the only prerequisite for a positive perception of agriculture in the public. The formation of opinions on agricultural topics and thus trust in farmers is largely influenced by how a topic is presented in the media. Throughout the past 20 years, the majority of the German public obtained information on agriculture from television (TNS Emnid 2012). The majority of the German public considers media reports on agriculture to be balanced (TNS Emnid 2012), implying that the image of agriculture is strongly influenced by its representation in the media. Studies analyzing the effect of

the type of communication on the image of agriculture among German residents revealed that while direct contact with agriculture through conversation with farmers had a positive influence on the image, contact with agriculture via media (media-mediated agriculture) had a negative influence. Agricultural topics often discussed in German media include rising meat prices, meat scandals, animal husbandry conditions (associated with so-called factory farming), and the use of antibiotics (Helmle 2010; Wolfram et al. 2019). Thus, these critical portrayals at least partly explain the moderate level of trust in German farmers observed in our survey.

Rating of digital farming technologies

Regarding studies on the public acceptance, one has to bear in mind that the results have to be seen in the context of cultural and geographical differences (e.g., societal values, religion) shaping public attitudes (Srite and Karahanna 2006; Costa-Font and Gil 2009; Bearth and Siegrist 2016). The literature reveals that research on the public acceptance of technologies is mainly concentrated on the developed world (especially North America and North-Western Europe) and does not provide sufficient insight into the situation in developing countries (see also Gupta et al. 2012; Bearth and Siegrist 2016). Thus, it has to be considered that this study was conducted in Germany, a country with a low share of the population being employed in the agricultural sector.

The respondents' evaluation of the statements to DFT was quite positive—both in the general statements and in the four specific DFT. Given our explanations of DFT, most agreed that they show potential in the areas of animal welfare as well as environmental protection and advocated their use in practice. The similarly high level of agreement on the use of DFT in practice and on subsidies for farmers using them, underlines the seriousness of respondents' answers, as they were well aware that taxpayers' money would be used for this purpose. Since we asked about the consent to the use of taxpayers' money in the survey, our attitude-oriented approach also included an intention or willingness to act-component (see Schäfer and Keppler 2013). In the Dutch survey by Boogaard et al. (2011a), agreement on a higher willingness to pay for both environmental and landscape care and subsidies to farmers (if they can only stay in business with governmental subsidies) was more subdued compared to our results, but still more supportive than negative. Also in studies conducted in the UK (Bennett 1997), Spain (María 2006), and Germany (Weinrich et al. 2014), the majority of respondents indicated a willingness to pay for improved animal welfare standards (e.g., phase-out use of cages in egg production, pasture-raised milk). However, a meta-analysis by Lagerkvist and Hess (2011) on consumer willingness to pay for farm animal welfare showed that French and German

consumers exhibited higher, and Danish consumers lower willingness to pay for farm animal welfare than consumers from other countries such as the US, UK and Sweden. The result of this meta-analysis highlights once again that the results concerning the consent to state subsidies for farmers using DFT, have to be seen in the context of the country of survey of the study.

The influence of socio-demographic factors (Devlin 2005; Sharp and Tucker 2005; Devine-Wright 2008; Boogaard et al. 2011a), knowledge (Devlin 2005; Devine-Wright 2008; Boogaard et al. 2011a; Stiehler 2015), general attitudes (Lucke 1995; Grunert et al. 2003; Kollmann 2004; Sharp and Tucker 2005; Boogaard et al. 2011a; Stiehler 2015), and trust (Dunlap et al. 1993; Slovic 1993; Cvetkovich and Lofstedt 1999; Eiser et al. 2002; Roosen et al. 2015; Stiehler 2015; Bearth and Siegrist 2016) on acceptance has already been revealed many times. Socio-demographic variables such as gender, age, and education not only influence general views of agriculture (Haartsen et al. 2003; Sharp and Tucker 2005; María 2006) but partly also the attitudes toward the benefits of DFT, as shown in our study. For instance, Boogaard et al. (2011a) showed that older people were more positive about contemporary agricultural production methods, more open-minded toward modern production processes, and had a higher willingness to pay for added values such as maintaining nature. María (2006) showed that younger people were more critical than older ones in terms of animal welfare on farms and found a higher willingness to pay a surcharge to improve animal welfare among younger or middle aged people than among older ones. However, Kühl et al. (2019) applied a picture-based approach to analyze the overall acceptance of different husbandry systems for dairy cattle, with socio-demographics such as gender, age, and education not driving any significant differences in acceptance. Although there were also a few studies to the contrary, a review of the social basis of environmental concerns by Van Liere and Dunlap (1980) confirmed that age is predominantly negatively correlated with environmental concerns. Our results point in a similar direction as the findings of María (2006), showing that younger (< 40 years old) rather than older people agreed to a state subsidy for farmers using DFT.

Although points of contact between the population and agriculture are becoming fewer, our results did not reveal a significant effect of the size of place of residence on the attitudinal acceptance of DFT. Numerous studies have dealt with the hypothesis of a difference in agricultural and environmental attitudes between rural and urban populations (e.g., Van Liere and Dunlap 1980; Freudenburg 1991; Sharp and Tucker 2005). Yet there appears to be no clear overall tendency. For example, in their survey, Sharp and Tucker (2005) did not identify a clear pattern between the place of residence on the one hand

and livestock welfare and environmental concerns on the other hand. Similarly, our results did not demonstrate any significant impact of the size of place of residence on the attitudinal acceptance of DFT. A possible explanation for this is the declining number of farmers in rural areas and the simultaneously increasing influx of urban population into rural areas, resulting in a growing proportion of rural residents without agricultural ties. Therefore, our chosen limit for the size of place of residence (5000) may have been still too high to recognize significant differences in the attitude toward agricultural issues.

The literature shows that personal contact with farmers as well as work experience in agriculture can have a positive effect on an individual's image of agriculture (Sharp and Tucker 2005; Helmle 2010; Wildraut et al. 2019), including attitudes toward modern animal husbandry and willingness to pay for values such as maintaining nature and landscape (Boogaard et al. 2011a). Sharp and Tucker (2005) found that people who grew up on farms had fewer livestock welfare and environmental concerns. However, their study did not reveal an impact of a mere visit to rural areas (e.g., for recreational purposes) on concerns about livestock welfare and the environment. Kühl et al. (2019) also did not identify significant differences in the overall acceptance of different husbandry systems for dairy cattle between respondents who had already visited a farm and those who had not. However, our results are not in line with the findings of Sharp and Tucker (2005), Helmle (2010), Boogaard et al. (2011a) and Wildraut et al. (2019), as our study did not show an effect of personal contact with farmers, including conversations on agricultural topics, on the attitudes toward DFT. We even found a slightly negative effect of work experience in the agricultural sector on the general attitudes toward the benefits of DFT and consent to the use of specific DFT. Thus, our results regarding the influence of personal contact with farmers on the public acceptance of DFT cannot yet be clearly explained and require further studies to substantiate them. The increased negative general attitudes toward the benefits of DFT and lower consent to the use of DFT by respondents with work experience in the agricultural sector could partly be explained by negative experiences with using DFT. It is not known how many of the respondents with work experience in the agricultural sector had explicit experience with DFT. However, there exists well-founded evidence that the use of DFT still poses certain challenges that could be reflected in our results. Challenges of digital agriculture, are, amongst others, high complexity of interpretation of the collected data and thus a lack of decision support for the average user, and too high costs to implement them nation-wide (Reichardt and Jürgens 2009; Weersink et al. 2018). For the public to be convinced of technologies such as DFT, first and foremost, its users must be convinced so that they can convey this positive image to the public.

According to the findings of our survey study conducted in Germany, accepting DFT and agreeing to their subsidization is mainly based on positive general attitudes toward farming and trust in farmers. Altogether, these determinants had a greater impact on the attitudinal acceptance of DFT than other variables such as socio-demographics. Thus, our results confirmed the role of values and beliefs shaping peoples' attitudes and decisions (Lusk et al. 2014), including agricultural issues. To alter values and beliefs, however, is not easy to realize in practice: Trust in risk regulators is difficult to build, but is quickly lost (Frewer and Salter 2002). Using the example of novel food technologies, Siegrist (2008) emphasized that advantages and disadvantages of technologies may not always be obvious, thus being difficult for the public to evaluate. About 87% of the EU population has never worked with a robot, regardless of its field of application (Eurobarometer 2012). This reinforces the explanation that it is difficult to assess the risks and benefits of technologies without respective experience. In addition, to form a well thought out and balanced opinion on agricultural topics can be difficult with a low level of knowledge of present-day agriculture. Therefore, trust in the user of a technology is a relevant factor for the public acceptance of agricultural innovations. In this context, it is important to keep in mind that the topic of digitalization in agriculture is rather specific and new. Therefore, especially when decisions cannot be made on the basis of sound knowledge, values and trust are central factors in making decisions that are not fully rationally justified (Sparks et al. 1994; Siegrist 2008).

As our results showed, the public values some positive aspects of modern agriculture such as food quality and low prices and perceives the sector to be innovative and technically advanced (see also Boogaard et al. 2008). The spontaneous associations confirmed that the addressed DFT are considered to be innovative and relevant to the future by many. However, the public attitude toward modern agriculture, including modern animal farming, is ambivalent as there are also many negative impressions in the public. Modernity and technical progress in agriculture are not considered to be negative in general, but the loss of values, traditions, and naturalness (Alrøe and Kristensen 2002; Lassen et al. 2006) often accompanying technological innovations are not appreciated. This dilemma is a reason why modern agricultural production is often criticized by the public as it contradicts the deeply rooted vision of romantic, idyllic family farms and museum agriculture in European society (Boogaard et al. 2011b; Simons et al. 2019).

Looking at the categories of spontaneous associations, it seemed that some of the respondents impulsively referred to events in the past that have remained in their memory due to media coverage, as issues such as concerns for environmental protection, industrial agriculture, or

animal cruelty are often addressed in German media (see Helmle 2010; Wolfram et al. 2019). In group discussions on the understanding of modern agriculture in Germany by Simons et al. (2019), terms such as “mass production” and “less contact between humans and animals” were mentioned by the respondents, similar to participants in our study. There, many individuals spontaneously associated the idea of *Industrialization* with the two pictures of the milking robot and the feeding robot that we showed them. It was noticeable that the spontaneous associations with the two DFT for dairy farming were more negative compared to the ones for crop production. The negative connotation of DFT in dairy farming may be shaped by the high level of concern for animal welfare in the Germany public. This was confirmed by previous studies conducted in Germany, showing that animal welfare was consistently ranked the highest among a multitude of public demands and wishes for agriculture (see TNS Emnid 2012; Luy et al. 2019). A survey among EU citizens on their attitudes toward possible fields of application of robotics (Eurobarometer 2012) provides further explanations. While priority was given to space exploration and manufacturing, citizens were more empathic about the use of robotics for the care of people. When asked about a ban on robotics in application areas, care of children, elderly, and disabled people (60%) led the way, while only 6% voted for a ban in agriculture. It may be possible to draw parallels between the EU survey and our survey: when using robotics in the handling of living beings (human or animal), the views are comparatively critical. Comparing the two dairy farming technologies, the milking robot was associated with more negative terms than the feeding robot. This was mainly due to a more frequent association of the milking robot with *Animal Cruelty* and *Industrial Agriculture*. Therefore, it can be assumed that the milking robot was perceived as a technology used with the aim of increasing herd size and milk yield (performance-oriented), thus counteracting the wishful thinking about small family farms. In sum, the share of negative connotations associated with the milking robot (35%) in our study was consistent with the share of respondents in the UK study by Millar et al. (2002), who rated the milking robot as “not ethically acceptable” (32%). It is striking that in the general attitudes toward the benefits of DFT, the potential was seen primarily in an increase in the farmer's wellbeing. In comparison, the perceived potential for improving animal welfare was lower. This tendency was also evident in the evaluation of a milking robot by citizens of the UK (Millar et al. 2002). A reason for a critical attitude toward DFT may therefore be that benefits are seen more relevant to the farmer than to the animal or nature. With regard to the size dimension of agricultural robotics for sowing, the survey participants graded small swarm robots more positively than the large

autonomous tractor, largely due to increased safety and environmental concerns related to the large and thus heavy machine.

The more general criticism of the animal husbandry technologies shown included year-round indoor housing as opposed to free-range and pasture systems as a concept of ideal animal husbandry (Miele et al. 2011; Weinrich et al. 2014; Cardoso et al. 2016). Surveys in Germany revealed that animal husbandry of other species (pork, poultry) is judged at least as critically as cattle farming. This assessment was made by farmers and the broader public alike (Simons et al. 2019; Wildraut and Mergenthaler 2019). Likewise, crop production is often met with criticism in the German public. Aspects such as decreasing biodiversity, nitrate leaching, and the desire to reduce pesticide use are just a few examples of the many points of criticism of agriculture in Germany. Consequently, DFT may be well accepted as a building block for improving animal welfare and a more environmentally-friendly production. However, the impact of these positive effects on the general acceptance of agriculture will probably be limited due to a lot of general criticism of agriculture in Germany, particularly in the case of animal husbandry.

Methodical considerations

Our study provides relevant results on public attitudinal acceptance of DFT in the German population. Consumer studies carried out on innovations in the food sector so far have measured various forms of acceptance. Willingness to pay, or acceptance, were measured as target variables in a large number of studies on, for example, gene technology, or nanotechnology (Bearth and Siegrist 2016). The fact that the use of DFT has a direct influence on farmers and animals, and only an indirect one on consumers, makes it harder to grasp public acceptance at the action and usage levels. Therefore, an approach based on models such as the technology acceptance model (Davis et al. 1989) was not appropriate for our study. Moreover, as our study did not cover any action component (e.g., purchase of a product), our measured target variables cannot be interpreted as “acceptance”, as defined in the literature (see Lucke 1995; Schäfer and Keppler 2013). However, it has to be noted that the construct “attitudinal acceptance” by Kollmann has been mainly applied to innovation in use, although it is described as an independent construct that precedes the purchase of a product (Kollmann 2004).

The evaluation of the consent to state subsidies for farmers who purchase DFT, however, provides first relevant indications. Further studies on the actual willingness of consumers to pay for improving environmental and livestock conditions by means of DFT (action phase) should

be pursued, for which choice experiments would be a suitable methodological approach (see also Lagerkvist and Hess 2011). Presumably, in terms of willingness to pay for higher animal welfare or environmental protection standards, there might be a different outcome, depending on the study being methodologically based on a choice experiment or on Likert scales for provided statements, as was the case in our study. Thus, the results of our study are not yet sufficient for evaluating the overall acceptance of DFT. Nevertheless, with our study we are taking a necessary step that enables an initial assessment of the situation in Germany, on the basis of which further methodological procedures can be developed.

The combination of the two methodological approaches emerged to be particularly valuable. Based on the results of our study, we recommend that surveys on the acceptance of technologies that are not comprehensively known to the general public should not be structured purely text-based. The results demonstrated that asking for the evaluation of provided statements (Likert scales), on the one hand, and spontaneous associations with pictures showing DFT, on the other hand, leads to a multi-faceted assessment. As described in the literature, the pictures showing DFT contributed to the release of feelings and emotions (Cvetkovich 2003), as evidenced by emotional references such as “animal suffering”, “poor cow”, or “poison”. Our results confirmed the finding of Slovic et al. (2007) that integrating affective impressions may lead to higher efficiency, especially if the assessment of a given issue is complex. In fact, whereas the evaluation of DFT was largely positive in the given statements, the spontaneous associations revealed a much more differentiated picture. Asking for spontaneous associations proved to be a suitable methodical approach to obtain valuable indications of perceived benefits and risks of DFT from the public. Therefore, spontaneous associations provide a sound basis for determining concerns in the public, which need to be addressed for developing approaches to strengthen public acceptance.

Public acceptance is to be considered against a cultural and also media background in which public perceptions arise. Since the general image of agriculture varies from country to country, it can be assumed that this heterogeneity also applies to the public acceptance of DFT. The results of our study conducted among the German population revealed that general attitudes and values influence acceptance of DFT. However, attitudes and values are to a considerable extent anchored in a cultural and socio-economic context. Therefore, we suggest similar future studies in further countries in order to gain insights that are not limited to the German public. Furthermore, integrating respective components into the framework of the survey could provide valuable indications of the extent to which public opinions on agriculture are influenced by its representation in the media (e.g., type of media used).

Implications and conclusions

The high share of undecided respondents in questions concerning general attitudes toward agriculture, trust in farmers, and the assessment of DFT shows that there is a need to inform the public in an objective way. However, more comprehensive, balanced information on a topic may not necessarily always result in greater acceptance of an issue (Scholderer and Frewer 2003; Weary and Keyserlingk 2017; Wuepper et al. 2019), as opinions are based not only on experience and knowledge but also, and very importantly, on values and beliefs (Te Velde et al. 2002). Since opinions on a topic are thus very deeply rooted, simply providing information in order to change them will most likely be insufficient (Grunert et al. 2003). In the study by Millar et al. (2002) on the consumer acceptance of the milking robot in the UK, a short description of the technology was provided. However, 29% of respondents answered they were unable to judge whether the milking robot was “ethically acceptable”—a similar proportion of undecided consumers could be found in our study regarding the general attitudes toward the benefits of DFT, although Millar et al. did provide more background information in their survey. Ventura et al. (2016) have already addressed the question of whether a self-guided farm visit (carried out on a 500-head dairy farm in North America) can contribute to changing perceptions, concerns, and values about dairy cattle. In their study, a farm visit helped to resolve some concerns of the public, while at the same time other concerns arose. Studies carried out in Germany on the acceptance of animal husbandry systems confirmed that merely providing information does not necessarily lead to greater acceptance in the public. In comparison, a personal dialogue between the public and farmers had a stronger, positive effect regarding some issues, such as conditions under which farm animals are kept. In this context, it is interesting to note that the effect of a personal dialogue was particularly strong in the statement “Technology makes the work of animal owners easier and farm animals can be better cared for” (Wildraut et al. 2019). Although personal contact with a farmer had no significant impact on the attitudes toward the benefits of DFT in our study, the dialogue between farmers and consumers is essential and an important step in the process of building trust between farmers and the public. In line with the literature, we see that public acceptance of DFT is not only determined by the characteristics of technologies and the associated impacts on animals or nature. Rather, the public must have trust in the farmer, who is seen as the person responsible for the most appropriate use of DFT, thus deciding on a possible improvement of animal welfare and environmental protection. Weary and Keyserlingk

(2017) analyzed various strategies for dealing with public concerns about dairy-cow welfare. They concluded that engagement with the public is more successful than efforts to educate the public. Two-way conversations in particular are effective when addressing the most concerned people, possibly directly on a farm that is being opened up to the public. These conversations may also help farmers understand the concerns of the public, and help the public put itself in the farmers’ shoes. Regarding farmer-consumer dialogues, public interest in technical details of agricultural processes is probably limited. Information should be focused on fundamental values and take into account emotional components. To this end, the potential of DFT for animal welfare and environmental protection may serve as a supportive argument. Importantly, in this context, farmers, and especially trainees in agricultural education, should be trained in communication strategies with the public. For farmers, it is becoming increasingly necessary to recognize and develop social communication skills as an entrepreneurial competence.

Our study revealed that the need for considering the public acceptance of an increasing use of DFT should not be neglected. Although our results are limited to the German public, they indicate the urgent need for other countries to involve the social component at an early stage when evaluating DFT. Regarding the social component, not only research and farmers should become active when establishing technologies on the market. Also innovators and developers have to involve the public as early as possible in a development process. Initial studies on responsible research and innovation (RRI) aiming to guide socially and ethically acceptable innovation (Stilgoe et al. 2013) are already addressing relevant points in this regard (see Rose and Chilvers 2018; Bronson 2019; Eastwood et al. 2019). To this end, in agriculture, more intensive and coordinated cooperation between public, private, and civil society actors involved in the development of technical innovations needs to be established (Rose and Chilvers 2018). End-users and consumers should be involved in a socio-ethical discussion, for example relating to farmer-technology interaction or animal-technology interaction, using workshops or citizen panels, so that critical feedback can be taken into account early on. The beginnings of RRI lie in a social and political European setting, which is why the focus of its application lies in the European and North American context, without previous application to DFT (Eastwood et al. 2019). Therefore, an extension of RRI to digital agriculture as well as to other countries is indispensable.

In summary, the results of our study prove that future research on digital agriculture must put more emphasis on the analysis of public response to agricultural modernization and its dynamics in order to ensure an appropriate image of increasingly automated agriculture.

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Compliance with ethical standards

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