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Perception and acceptance of robots in dairy farming—a cluster analysis of German citizens

Greta Langer[1] · **Sarah Kühl**[1]

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Abstract
Societal attitude acceptance can influence the digital transformation in agriculture. Digital technologies, such as robots in dairy farming, can lead to more sustainable, animal welfare-friendly and consumer-oriented milk production. This study used the example of the milking and feeding robots to investigate whether society accepts the use of robots in dairy farming and whether there are differences in society based on perceived risks and opportunities of digitalization in dairy farming and acceptance. To this end, an online-based study was conducted with a total of 1007 citizens in Germany. Overall, the respondents in this study suspect that the use of robots in dairy farming is associated with various risks but also with opportunities for society and for farmers in particular. However, these attitudes are quite heterogeneous. Four clusters could be identified: "proponents of robots", "indifferent citizens", "skeptical citizens", and "critical supporters of robots". Proponents of robots see only opportunities and little risks, whereas the critical citizens perceive not only opportunities but also many risks of using robots in dairy farming. The indifferent citizens show a rather indifferent attitude, in contrast to the skeptical citizens, who reject the opportunities at the societal level, while they agree with the opportunities of robots for farmers. This research contributes to understanding societal attitudinal acceptance and highlights differences in society that can help inform future decisions about the development and adoption of robots in dairy farming.

Keywords Digital transformation · Societal attitude acceptance · Risk perception · Opportunity perception · Dairy farming robots

Introduction

Technological and, especially, digital development is increasingly being leveraged in agriculture. Digital Farming refers to similar technological developments in the agricultural sector as "industry 4.0" does in the industrial sector. Digitalization in agriculture essentially comprises two stages of development: precision and smart farming, where precision farming is an information-based approach and smart farming is knowledge-based. In the first approach, information is digitally processed to provide decision support to farmers. In the second approach, the entire "farming process" can be optimized through the use of information and communication technologies, where machines gather information, process data, and provide autonomous decision support (Bovensiepen and Hombach 2016). In recent years, a wide range of precision livestock farming technologies (PLF technologies) has been developed in the field of dairy farming. These primarily include feeding and milking robots and automatic manure removal systems (Digital Agriculture Network 2021). Such PLF technologies support farmers in their daily work and inform them via human–machine interfaces, e.g., about deviations in animal health data (Schukat et al. 2019; Akbar et al. 2020; Akhigbe et al. 2021). However, farmers appear to be hesitant in adopting such technologies (Mohr and Kühl 2021) and the diffusion of PLF technologies in dairy farms has been rather heterogeneous (Rutten et al. 2018). According to the International Farm Comparison Network (IFCN) (2020), the percentage of dairy cows milked by robots ranges from less than 1% in some countries to over 30% in others, with robotic milking being most widespread in Europe. In general, the use of robots on

✉ Greta Langer
greta.langer@uni-goettingen.de

Sarah Kühl
skuehl@gwdg.de

[1] Department of Agricultural Economics and Rural Development, University of Goettingen, Platz der Goettinger Sieben 5, 37073 Goettingen, Germany

dairy farms has increased significantly since the 1990s and continues to grow, although other types of robots are still in the early stages of development (Wendl 2015).

In many ways, however, digital farming is already being discussed as a “miracle solution” to meet future challenges in agriculture (Federal Agency for Agriculture and Food Germany 2021). Digitalization is supposed to help produce significantly more food in an environmentally friendly, sustainable, and animal welfare-friendly manner in the face of an increasing shortage of skilled labor and limited resources (Wolfert et al. 2017; Shepherd et al. 2018). However, PLF is also changing the way farming is done, what it means to be a farmer, and how the profession of farming is perceived by society (Block and Long 2016; Henchion et al. 2022). Digitalization and automation of agricultural work are seen primarily as an alienation from a social perspective (Driessen and Heutinck 2015). For example, dairy cows increasingly appear as production resources in strictly monitored production facilities (Stuart et al. 2012). Digitalization intensifies the development of industrialization of agriculture and thus contradicts existing public perceptions of a small-scale farming system (Short 1992; Block and Long 2016; Pfeiffer et al. 2020). In addition, it is assumed that the future focus of livestock farmers will lie on the interpretation of data, and the contact between farmer and livestock becomes irrelevant: “farmers become more concerned with data management rather than with animal husbandry, [therewith] animal welfare issues could arise” (Block and Long 2016, p. 552). Social-ethical concerns related to digital agriculture exist on the part of farmers and society (Rose and Chilvers 2018) but have received little attention in research (Henchion et al. 2022), even though the relevance for societal acceptance analysis of agricultural innovations has been recognized (Asveld et al. 2015; Frewer 2017; Rose and Chilvers 2018; Pfeiffer et al. 2020).

For example, the responsible research and innovation (RRI) approach demonstrates the need to anticipate and assess societal expectations regarding research and innovation to support the design of inclusive and sustainable innovation (European Commission 2020). Specifically, in the context of precision and smart dairy farming, there is a requirement for citizens to be involved in the socio-ethical discourse of digitalization agriculture to develop a more sustainable dairy production (Eastwood et al. 2019). The inclusion is important to ensure a successful implementation of digitalization and to prevent the gap between socially desired images (personal values) and real farming practices from becoming even wider than it already is in many areas of agriculture (Verbeke et al. 2007; Scientific Advisory Board Agricultural Policy 2015). There are several conceptualizations of RRI, including the anticipation, inclusion, reflexivity, responsiveness (AIRR) concept. However, prior to the inclusion of diverse stakeholders, the AIRR concept incorporates future-related analyses (anticipation) to identify potential economic, societal, and environmental impacts linked to precision and smart dairy farming. To date, the RRI approach has failed to adequately address the participation of citizens and consumers in this context (Rose and Chilvers 2018; Eastwood et al. 2019). According to the AIRR indicators proposed by Eastwood et al. (2019), public opinion surveys should be included as foresight exercises into the anticipation step. Building upon this, future scenarios for smart dairy farming can be developed in further steps of the approach, followed by the inclusion of stakeholder perspectives into technology development.

The aim of this paper is therefore to gain initial insights into societal acceptance and to identify possible differences in society (in the form of citizen segments) based on the perceived risks and opportunities of digitalization in dairy farming (specifically using the example of milking and feeding robots) and attitudinal acceptance. The results help to develop possible solutions and strategies for improving the societal acceptance of robots in dairy production. The analysis is based on an online survey with 1007 citizens in Germany. A principal component and cluster analysis are applied.

First, the current state of research on societal acceptance in agriculture is presented, followed by a definition of the term acceptance. Then the methodological procedure is explained, and the results are presented. Subsequently, these are critically discussed with the existing literature and recommendations for action and limitations are derived.

Research background

Societal acceptance toward the digitalization of agriculture

In the course of societal acceptance research, many models of investigation and attitudes have been developed over a long period of time with different focuses and considering various influencing factors (Bredhal et al. 1998; Ronteltap et al. 2007; Frewer et al. 2011; Huijts et al. 2012). Gupta et al. (2012) noted that socio-psychological factors in particular influence the societal acceptance of technologies. In this context, the perception of various potential opportunities and risks associated with the respective technology is an important predictor for the acceptance of a technology (Schweizer-Ries et al. 2010; Huijts et al. 2012; Liebal and Weber 2013; Sonnberger and Ruddat 2016). Rejection of a technology is stronger the more negatively the risks are evaluated. If many opportunities are associated with a technology, there is a positive effect on acceptance (Bredhal et al. 1998). However, it is generally assumed that societal acceptance is greater when benefits become tangible and concrete (Bredhal et al. 1998; Burgess 2010; Frewer 2017). The use of technologies in agriculture will therefore only be accepted by society if the opportunities of digitalization are recognized and its risks declared inapplicable (Beghin et al. 2021). In this context, it is noteworthy that digitalization has been integrated into livestock farming since the 1970s. Milking and feeding technologies have made significant progress in recent decades, accelerated by the advent of robotics in this field (Jungbluth 2017; Hostiou et al. 2017). As a result, numerous opportunities for improving livestock management developed.

The trend of increasing automation is evident in German dairy farming, with a steady growth in interest among dairy farmers in robots (Simões Filho et al. 2020). More than half of the dairy farmers in Germany choose a milking robot when deciding for a new milking system (Beber et al. 2021). Additionally, German dairy farms follow an intensive capitalization and expansion strategy and are the leading dairy producers in the EU. They are recognized as pioneers in the field of dairy farming (Ibid.). However, dairy production in Germany, as well as in other countries, faces various social and operational challenges such as animal welfare, climate protection, and price pressure. Scientists and policymakers believe that the presence of conflicting objectives within these challenges necessitates considering smart dairy farming as a promising solution to address both the societal issues associated with dairy farming and the operational challenges faced by dairy farmers (Dorfner 2018; Eastwood et al. 2019; Zanin et al. 2020). Hence, both Germany and other EU countries are increasingly emphasizing the digital transformation of the sector (Network Digital Agriculture 2021), rendering Germany an appropriate exemplification for the current research project.

In this regard, it is of considerable importance to use the example of milking and feeding robots to find out whether citizens perceive opportunities and risks of this technology and specifically what these are. Only if this becomes evident further steps can be considered to foster societal acceptance, which could also be extended to other countries (Krampe et al. 2021). Potential societal opportunities of robots in the dairy sector can be identified as improving animal welfare and creating more transparency in dairy production (Stuart et al. 2012; Henchion et al. 2022). PLF technologies generate data that provide information about health status and feeding and milking behavior, which can lead to increased animal welfare, as well as improved food safety (Krampe et al. 2021). Digitalization can also help bring consumers and farmers closer together; for example, data informs citizens about the lives of farm animals and can make particularly good farm practices visible (Carolan 2015). Open-access data provides insights into the extent to which PLF technologies actually contribute to solving societal problems, such as promoting food safety and sustainable management (Carolan 2015; Wolfert et al. 2017). A more efficient production and provision of food (Vierboom et al. 2006), considering the conservation of nature and animals, is also identified as another societal benefit of digitalization (Godfray and Garnett 2014).

Furthermore, digitalization can bring benefits beyond those that directly impact citizens, and these can also influence societal acceptance. If only a few personal positive aspects are associated with a technology, the view that industry, users, or manufacturers benefit from these technologies shapes the societal perception (Frewer et al. 2011). In this context, considerations play a role as to which (negative or positive) consequences are caused by the object of acceptance that could be relevant for other social groups, such as friends, family, future generations, or even for nature (Bredhal et al. 1998, p. 256). Thus, for the present research context, society's perception of the opportunities of PLF technologies for farmers is also relevant. Improved work life balance, increased flexibility, efficiency and productivity, labor savings, financial benefits, and improved animal monitoring are described as the main opportunities of using robots for farmers (Stuart et al. 2012; Regan 2019). However, to fully harness the opportunities of digitalization, farmers must be willing to use and invest in such technologies. Moreover, they must learn to properly utilize digital technologies, analyze and interpret the generated data, and effectively apply the collected data knowledge (Higgins et al. 2017). In turn, farmer adoption is influenced by various factors such as perceived usefulness, ease of use, social norms, and normative and control beliefs (Paustian and Theuvsen 2017).

In addition to the opportunities, perceived risks that could be of social relevance are also discussed in the literature (Bredhal et al. 1998; Frewer et al. 2011; Gupta et al. 2012). In the agricultural technology acceptance discourse, perceptions toward interventions in nature (actions taken by humans that affect the natural environment), loss of traditions, and treatment of animals have been found to be particularly relevant (Boogaard et al. 2011a). These aspects can be subsumed under the concept of naturalness (Segerdahl 2007). Lack of naturalness is mainly related to perceived risks of a technology (Sjöberg 2004; Ronteltap et al. 2007). In the agricultural context, naturalness is also associated with "freedom" and "extensive, small-scale agriculture", with freedom being defined as animals and plants being able to behave according to their natural instincts (Clark et al. 2016). However, robots tend to increase herd size, implement more efficient management practices, and lead to standardization and intensification of milk production (Stuart et al. 2012). Rose et al. (2021) assume that this will lead to smaller farms leaving the dairy industry. Increased robotization and automation of agriculture may also cause farmers to lose experiential and observational values, to

Table 1 Overview of opportunities and risks of precision dairy farming technologies

Opportunities	Risks
Improvement animal welfare and animal health	Potential mistreatment of animals
Increased transparency in the value chain	Data security
Digital networking (connection farmer and consumer)	Reduction of naturalness and tradition
Improved food safety	Increased standardization and intensification
Efficient production	Negative impact on natural environment
Better work-life balance for farmers	Disconnection farmer–animal
Enhanced employee motivation/support	Shifts in the labor market and employment patterns
→ Positive side of modernity	→ Negative side of modernity

Source: own illustration

pay less attention to their dairy cows, and thus to a reduced or disconnected farmer–animal connection (Krampe et al. 2021; Rose et al. 2021). This could result in a variety of risks to animal health and welfare (Regan 2019).

In the course of advancing digitalization, the issue of data security has also gained importance (van der Burg et al. 2019) and represents a potential risk (Regan 2019). Furthermore, the uncertain development in the labor market is also critically discussed; robots could replace farmers in the long term (Bronson et al. 2018; Rotz et al. 2019). Undoubtedly, digitalization will reduce manual labor but also substitute many existing farm worker jobs and reduce traditional farming practices (van der Burg et al. 2019; Rose et al. 2021).

So far, there is a lack of evidence on how society perceives and evaluates the potential risks and opportunities of digital technologies for dairy farming (see overview in table one) as described in the literature. However, Pfeiffer et al. (2020) found that critical concerns are expressed more frequently for technologies that relate specifically to animal husbandry than for technology that relates purely to crop farming. Basically, in the field of livestock production, a social dilemma exists between efficient and profitable production, the so-called positive side of modernity, and the reduction of naturalness and tradition, the so-called negative side of modernity (Boogaard et al. 2011a). Boogaard et al (2010) discovered that consumers value a combination of "seemingly contradictory aspects of technologies and nature" in agricultural production systems and specifically expect this for dairy production (Cardoso et al. 2016) (Table 1).

In the context of modern livestock farming, societal acceptance research has predominantly focused on animal welfare (Kendall et al. 2006; Deemer and Lobao 2011; Weary and von Keyserlingk 2017). Only few studies examine the overall societal acceptance of advancing digitalization. In the field of robotics, the milking robot in particular has been the subject of various societal acceptance analyses, as it was one of the first digital innovations in dairy production. However, the focus lies here again primarily on the interactions between humans, animals, and technology and the implications for animal welfare (Wenzel et al. 2003; Holloway et al. 2014) rather than on the overall societal perspective. A study by Millar et al. (2002) analyzed consumer attitudes toward the use of milking robots and noted that many socio-ethical concerns at that time primarily related to animal welfare, but other factors, such as impacts on the environment, were viewed more positively. Nevertheless, the majority of respondents did not welcome the introduction of robots in dairy production and called for specific legislation on the use of milking robots (Millar et al. 2002).

However, acceptance is an instable construct that can change depending on time and situation due to changing framework conditions and perceptions in society (Lucke 1995; Hüsing et al. 2002; Schäfer and Keppler 2014). For the field of robotics in dairy farming, there is a lack of new insights, and it is partly unclear to what extent society accepts digital technologies in different application areas of agriculture. Against the background of ambiguity in the literature described above, the question of societal acceptance is about ascertaining how the acceptance object is perceived by society and what risks and opportunities are associated with the usage of robots in dairy farming.

Concept of societal acceptance in the research context

Given the great complexity of the concept of acceptance, it is necessary to define societal attitudinal acceptance and adapt it to the research context of this study. The term acceptance is assumed to be a two-dimensional phenomenon consisting of an attitude dimension and an action dimension (Müller-Böling and Müller 1986), with the attitude component comprising the central dimension of acceptance, which precedes action acceptance (Schäfer and Keppler 2014). The concept of attitudinal acceptance is understood to be a positive attitude or assessment toward an object of acceptance. Moreover, acceptance must always be understood in the context of the three components subject, object, and context (Lucke 1995; Hüsing et al. 2002). Related to the present context, acceptance proceeds from a society (acceptance subject), which refers to an acceptance object (robots in dairy farming, e.g., milking and feeding robots) and manifests itself in an environment determined by the subject and object, i.e., the acceptance context (social and cultural framework conditions) (Hüsing et al. 2002, p. 24). Acceptance is thus not an immutable characteristic of a society as a whole, but rather a complex and multi-layered phenomenon. It requires suitable indicators (influencing factors) to make acceptance measurable (Hüsing et al. 2002).

For the present study, we examine the perceptions of risks and opportunities as object-related factors (Bredhal et al. 1998; Burgess 2010; Gupta et al. 2012). In the further course, subject-related factors such as socio-demographics, connection to agriculture, general attitudes toward dairy farming, and desired expectations of dairy farming are also associated with the object-related factors to emphasize individual differences in society. Since it is assumed that general values and attitudes of citizens (such as toward animal welfare, or dairy farming itself) are a basic prerequisite for acceptance, we include attitudes toward dairy farming in our study (Bredhal et al. 1998; Ronteltap et al. 2007; Pfeiffer et al. 2020). According to Boogaard et al. (2011a), the more familiar people are with agriculture and the more contact they have with it, the greater the acceptance. The factors of knowledge, experience, and contact with agriculture are therefore considered to have a large influence in the context of societal technology acceptance (Sharp and Tucker 2005; Boogaard et al. 2011b). In addition, desired expectations of agriculture are thought to influence societal acceptance toward technology use (Boogaard et al. 2011a), so we queried society's desired expectations of future dairy farming to identify a deeper understanding of differences in acceptance across society. In order to capture the variety of possible forms of acceptance, the acceptance dimensions listed in Fig. 1 were considered and queried according to the systematization approach of Sauer et al. (2005).

The dimensions of acceptance range from resistance (negative + active) and rejection (negative + passive) to acquiescence/indifference (passive; acquiescence with a negative bias, indifference with a positive bias) to endorsement (positive + passive) and engagement (positive + active acceptance). Sauer et al. (2005) extend this dimension by conditional acceptance (positive + with an active tendency). This dimension implies an acceptance that is based on rational considerations and is linked to certain conditions or demands of the acceptance subject.

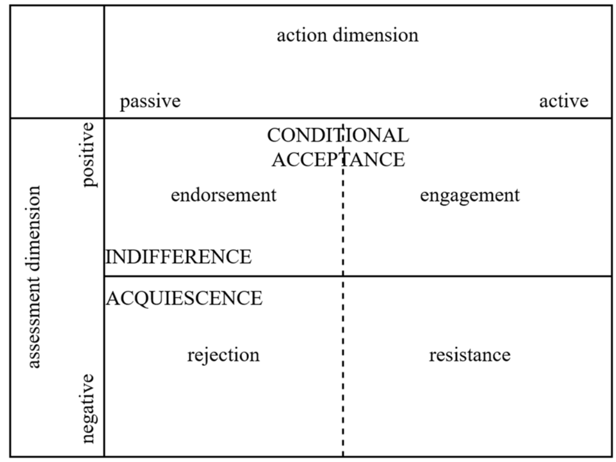

Fig. 1 The acceptance dimensions according to Schweizer-Ries et al. (2010, p. 11) and Sauer et al. (2005: 25)

Material and methods

Study design and data collection

In September 2021, a standardized online survey was conducted among citizens in Germany. The participants were recruited via a professional field service provider. The online questionnaire was pretested in advance by a subsample (n = 100) of the online panel with regard to comprehensibility and technical procedure. A total of 1105 individuals completed the survey. The questionnaire included a quality check: to ensure that all participants read the questions with care they were asked to select the answer "fully agree" by one item in a statement matrix. Participants who did not answer the question correctly were already discarded during the survey. Additionally, of the 1105 participants, 98 cases were deleted from the final data set because they answered the questionnaire in less than half the median completion time (median = 799 s, half median = 399.5 s). This results in a final sample size of n = 1007. Quotas according to the population of Germany were set for gender identity, age, education, and size of place of residence (rural or urban) to obtain an approximately representative sample. The study data were collected online, and only individuals with internet access who had registered with a professional field service provider were able to participate. Therefore, the sample is not fully representative, as it does not consider potential differences between internet users and non-internet user.

The questionnaire was divided into several parts. In the first part, sociodemographic characteristics were recorded using nominal scaled questions. Then, respondents were asked how they perceived their knowledge of and experience with agriculture and dairy farming. In addition, the item "I have friends, acquaintances and/or family members who work in agriculture" was used to query their relationship to agriculture. Furthermore, attitudes toward dairy farming and expectations of future milk production were surveyed on a five-point Likert scale ranging from 1 = "fully agree" to 5 = "fully disagree". These statements are based on the items according to Boogaard et al. (2011a), Kayser et al. (2012), and Pfeiffer et al. (2020) (e.g. “It is important to me that the dairy industry continues to be progressive and innovative in the future”). The next part of the survey focused on the two object-specific influencing factors. At this point, respondents were asked specifically about the two robots in dairy farming. However, no further information on the robots was provided at this point and no distinction was made between the use of the robots in conventional or organic dairy farming. The statements on the object-related factors were also measured using a five-point Likert scale and were based on statements from previous societal acceptance studies related to agriculture. Thus, the statements correspond to the categories risks, opportunities on the societal level and opportunities for farmers (see Appendix Table 6). Finally, participants were asked to rate their acceptance of the use of robots in dairy farming. The acceptance dimensions described in Fig. 1 (Sauer et al. 2005; Schweizer-Ries et al. 2010) were queried on five-point Likert scales; statements are shown in Table 7 in the appendix.

Statistical analysis

The data were analyzed using the statistical program SPSS 27. Descriptive statistics were first conducted to describe the demographic characteristics of the sample. A principal component analysis and a cluster analysis were used to examine the data set in terms of the research question. In order to reduce the number of items and capture the most important dimensions contributing to the acceptance of citizens' attitudes, a principal component analysis with varimax rotation was applied. Variables that were highly correlated and loaded on one factor were combined into one factor. Orthogonal varimax rotation was used to facilitate interpretation of the factors. This allowed the variance of squared factor loadings per column to be maximized. Before this, the baseline data was tested for suitability using the Kaiser–Meyer–Olkin criterion (KMO), Bartlett's test and the variable-specific measure of sampling adequacy (MSA) (Backhaus et al. 2016). This measures whether there are correlations between variables (Bartlett's test) and a notable relationship between the variables (KMO, MSA) (Brosius 2011). In addition, values with loadings below 0.5 are considered unsuitable for principal component analysis and were thus excluded from further calculations (Kaiser and Rice 1974). In several runs, all variables that had loadings on more than one factor were removed from the analysis. This resulted in a well-defined assignment of each of the items to only one factor (Backhaus et al. 2016). The extracted factors served as the basis for the cluster analysis.

The purpose of the cluster analysis was to build homogeneous groups out of a heterogeneous population based on the identified attitude components (Hair et al. 2010). The cluster analysis was performed in three steps. First, a hierarchical clustering method was conducted using the single-linkage procedure to identify and eliminate outliers. Then, using Ward's method, respondents could be clustered together. The goal of this procedure was to combinate the objects that increase the variance within a group the least and form the most homogeneous clusters. A systematic comparison was used to determine the number of clustering opportunities based on the dendrogram and the application of the elbow criterion (Backhaus et al. 2016). To refine the solution and to improve the homogeneity of the groups, a K-Means procedure was applied. The final result of the cluster analysis was checked for its quality with a discriminant analysis (Bühl 2010). To evaluate the heterogeneity of the clusters, the significances of the results were determined using post hoc tests (Everitt and Skrondal 1998).

Results

Sample description

Table 2 shows the distribution of the sociodemographic attributes in comparison to the German average. The distribution of the study is representative for the German population in terms of gender, age structure, size of place of residence, and education level. Solely the distribution of the sample in the category “without a degree (yet)” is under-representative with 0.4%, whereas the degree “High school diploma” with 20% can be considered as slightly over-representative compared to the German national average.

With regard to their connection to agriculture, almost two-thirds of the respondents (65.6%) estimated their level of knowledge in the field of agriculture and dairy farming as low. 78.0% of respondents stated to have no knowledge of digital technologies in modern dairy farming. 8.2% rated their level of knowledge in digital technologies in dairy farming as high, and 19.9% said they knew common farming practices in dairy farming. Only 9% of the respondents have work experience in agriculture or in the agricultural sector. Almost a quarter of the respondents (24.8%) stated to have friends, colleagues, or family members who work in agriculture. Thus, the sample shows a strong relation to agriculture. However, the majority of respondents had no or limited knowledge of digital technologies and common practices in agriculture and dairy farming.

Principal component analysis

The final results of the principal component analysis comprised three factors with a total of 22 items (Table 3) and was based on a correlation matrix. The KMO criterion showed a positive result for sample adequacy with a value of 0.926 (values above 0.6 are considered acceptable) (Backhaus

Table 2 Characteristics of the sample and national average (n = 1007)

Attribute	Sample (%)	German average (%)*
Gender		
Male	51	49
Female	49	51
Diverse	0	–
Age structure		
18–24 years	8	9
25–39 years	24	22
40–64 years	48	44
≥ 65 years	20	25
Size of place of residence		
< 20,000	39	40
20,000 to 100,000	28	28
100,000 to 500,000	16	15
> 500,000	17	17
Education		
University degree	16	17
High school diploma[a]	20	14
Higher secondary school[b]	32	31
Basic secondary school[c]	32	35
Without a degree (yet)	0.4	4

*Destatis (2020)

[a]German: Abitur/Hochschulreife/Fachhochschulreife (Gymnasium)

[b]German: Mittlere Reife/weiterbildende Schule ohne Abitur (Realschule)

[c]German: Volks- oder Hauptschulabschluss

et al. 2016). In addition, Bartlett's test of sphericity was statistically significant and showed correlation coefficients for the population with non-zero values. The reliability analysis showed that the internal consistency of the factors was adequate. Cronbach's alpha values of 0.891 (factor 1), 0.900 (factor 2), and 0.853 (factor 3) were obtained. All values were above the required minimum value of 0.6 (Bühl 2010; Hair et al. 2010; Backhaus et al. 2016). All performed tests for quality checks of the factor analysis imply that the variables are well suited for factor analysis. Together they explain 59.3% of the variance of all variables.

The first factor describes the risks perceived by citizens in relation to the use of robots in dairy farming and comprises eleven statements. The factor combines statements on economic, social, and ecological risks of digitalization, which can be relevant on both a personal and societal level. It is noticeable that participants agreed with most of the risks, although we observed a tendency toward indifference. In particular, however, this was the case for the risk that small farms will hardly be able to afford robots ($\mu = 1.80$; $\sigma = 0.836$). On the other hand, respondents showed indifference toward the risk that the farmer will be replaced by robots ($\mu = 3.25$; $\sigma = 1.233$).

Factor two—opportunities on the societal level—represents in seven items the citizens' assessment of the societal opportunities of the use of robots. The factor summarizes statements that can be assumed to be of particular interest to society as a whole. The factor indicates a certain indifference of citizens, as shown by the mean values (μ) (within the range of $\mu = 2.91$ to 3.29). For example, citizens were unsure if robots can help bring farmers and consumers closer together ($\mu = 3.29$; $\sigma = 1.028$).

The last factor—opportunities for farmers—implies in four variables the opportunities of robots for the daily work of farmers. This factor is characterized by significant agreement; the mean values range from 2.05 to 2.43. In contrast, the agreement for the last item "with the help of robots, farmers can reduce their costs in the long term" shows a slightly indifferent tendency ($\mu = 2.43$; $\sigma = 0.953$).

Results of the cluster analysis

After evaluating the dendrogram in the single-linkage clustering, four outliers could be removed, leaving 1003 data sets for further cluster analysis. A four-cluster solution was indicated as optimal. Discriminant analysis indicated a satisfactory classification accuracy of 99.7% for the cluster analysis. Further results of the discriminant analysis (eigenvalues and wilks lambda) proved high-quality results of the cluster analysis. The F-test results were significant, indicating heterogeneous values between the clusters. Thereby, factor three had the highest discriminatory power (F-value: 426.23). To characterize the formed clusters in detail and to test for significant differences between the clusters, a post hoc multiple comparison test was conducted (Bonferroni). This made it possible to determine which clusters differ in terms of the mean values of the variables (Backhaus et al. 2016) (Table 4).

The "**proponents of robots**" are the largest group and comprises 29% of the respondents. Compared to the other clusters, respondents in this cluster see only a few risks in digitalization. These respondents especially reject the statement that robots replace the work of farmers ($\mu = 4.26$; $\sigma = 0.787$) and that the usage of robots is unnatural ($\mu = 3.48$; $\sigma = 0.847$) compared to the other clusters. Additionally, they suspect opportunities of using robots for both society and farmers. Furthermore, the agreement on the opportunities for farmers is high. With an average age of 51, the respondents in this cluster are the oldest. As in the other clusters, the majority of this cluster lives in the city, but the place of residence does not differ significantly between the clusters (see Table 5). In addition, the level of education and the proportion of men are the highest (significant difference between clusters). The attitude of these clusters toward the

Table 3 Results of the principal component analysis

Factors and statements	FL[a]	μ[b]	σ[c]
Factor 1: Risks (Cronbach's alpha: 0.891)			
Using robots in dairy production no longer has anything to do with a natural production method	0.761	2.30	1.060
With robots, there is no personal interaction with the cows. The farmer becomes estranged from the animals	0.760	2.54	1.098
The use of robots exacerbates the alienation of consumers and farmers	0.753	2.77	1.023
By using robots, the farmer loses the opportunity to acquire knowledge through experience and observation	0.744	2.51	1.044
The use of robots may negatively affect the overall sustainability of agriculture	0.742	2.77	1.023
The use of robots increases the unemployment rate, particularly in rural areas	0.729	2.63	1.107
By buying a robot, farmers become very dependent on the digital infrastructure and its supply	0.666	2.30	0.949
Robots replace the work of the farmer; sooner or later the farmer's job will no longer be important	0.646	3.25	1.233
Digital systems are susceptible to data misuse and hacker attacks	0.561	2.25	0.951
Small farms will hardly be able to afford robots. Large farms will grow and small dairy farms will disappear	0.544	1.80	0.836
The use of robots can lead to even more standardization in livestock breeding and in the production of animal products	0.540	2.34	0.888
Factor 2: Opportunities on the societal level (Cronbach's alpha: 0.900)			
Our domestic dairy farming becomes better with increasing progress in digital technologies in agriculture	0.834	3.22	1.069
Robotics will help us to solve problems in agriculture and dairy farming	0.811	3.07	1.104
I believe that the benefits of robots in dairy farming predominate	0.796	3.02	1.063
The use of robots outweighs all negative aspects	0.770	3.05	1.084
Robots help to bring farmers and consumers closer together	0.705	3.29	1.028
Using robots improves animal welfare because discrepancies in the cows' behavior are detected more quickly	0.656	2.91	1.048
Using robots leads to more transparency in dairy production	0.618	2.92	0.999
Factor 3: Opportunities for farmers (Cronbach's alpha: 0.853)			
Robots facilitate the everyday work routine of farmers	0.818	2.05	0.903
Robots help farmers to increase their production	0.755	2.22	0.866
Digitalization and robotics improve the quality of life of farming families	0.753	2.35	0.918
Farmers can lower their costs in the long term by using robots	0.682	2.43	0.953

KMO (Kaiser–Meyer–Olkin value) = 0.926; explained total variance = 59.3%. Scale from 1 = "fully agree" to 5 = "fully disagree". [a]FL = factor loading. [b]μ = mean value. [c]σ = standard deviation. n = 1007

dairy industry is clearly positive. They consider the German dairy industry to be important. However, knowledge about agriculture and common practices in dairy farming is low or non-existent. In line with their assessment of robots, the participants in this cluster believe that it is important for the dairy industry to remain progressive and innovative in the future and to focus on the animals in dairy farming. They do not want milk to be produced with less technology. Apparently, however, this expectation has nothing to do with favorable prices, as it is not important to the cluster that dairy products continue to become cheaper in the future.

A total of 255 respondents (26%) were assigned to the cluster "**indifferent citizens**". They are characterized by a rather indifferent attitude. This is particularly evident when it comes to the opportunities of robots for society and farmers. However, compared to the other clusters, the opportunities to farmers are considered much more negative than by the other three clusters. The proportion of rural residents in this cluster is the lowest (31%), while the percentage of urban residents is the highest (69%). The level of education is also the lowest compared to the other clusters, with 10% having a university degree. The cluster considers German dairy farming to be important. However, it has little trust in the work of German farmers. Like the other clusters, they are not familiar with digital technologies in dairy farming and rate their level of knowledge about dairy farming as low. Nevertheless, it is noticeable that they are the only of the four clusters that tend to agree that they are familiar with common agricultural practices in dairy farming. Interestingly, it is important to the cluster that dairy farming remains progressive and innovative; they agree with the focus on the animal in livestock farming but considerably less so than the other three clusters. However, when asked whether they prefer dairy products to be produced in a more traditional way with less technology, they again show an indifferent attitude. Apparently, progress and innovation are not necessarily linked to the use of technology.

The "**skeptical citizens**" (27%) are characterized by strong agreement with the risks of robots in dairy farming. Especially the issue that small farms could disappear ($\mu = 1.23$; $\sigma = 0.437$) and that the contact between farmers

Table 4 Results of the cluster analysis

Factors and statements	Proponents of robots (n = 292; 29%)	Indifferent citizens (n = 255; 26%)	Skeptical citizens (n = 273; 27%)	Critical supporters of robots (n = 183; 18%)
Factor 1: Risks*** (F-value: 377.75)	0.90^bcd	0.25^acdc	− 0.62^abd	− 0.91^abc
Using robots in dairy production no longer has anything to do with a natural production method***	3.48^bcd (0.847)	2.62^acd (0.788)	1.74^abd (0.879)	2.09^abc (0.904)
With robots, there is no personal interaction with the cows. The farmer becomes estranged from the animals***	3.08^bcd (0.951)	2.51^acd (0.951)	1.55^abd (0.766)	1.85^abc (0.831)
The use of robots exacerbates the alienation of consumers and farmers***	3.78^bcd (0.830)	2.78^acd (0.798)	2.26^ab (0.994)	2.19^ab (0.851)
By using robots, the farmer loses the opportunity to acquire knowledge through experience and observation***	3.33^bcd (0.943)	2.67^acd (0.760)	1.86^ab (0.826)	1.92^ab (0.762)
The use of robots may negatively affect the overall sustainability of agriculture***	3.58^bcd (0.789)	2.84^acd (0.749)	2.15^ab (0.885)	2.24^ab (0.912)
The use of robots increases the unemployment rate, particularly in rural areas***	3.41^bcd (0.992)	2.68^acd (0.816)	2.17^ab (1.105)	1.98^ab (0.798)
By buying a robot, farmers become very dependent on the digital infrastructure and its supply***	2.74^cd (0.948)	2.65^cd (0.748)	1.72^abd (0.756)	1.95^abc (0.807)
Robots replace the work of the farmer; sooner or later the farmer's job will no longer be important***	4.26^bcd (0.787)	2.98^ad (0.856)	2.95^ad (1.28)	2.44^abc (1.16)
Digital systems are susceptible to data misuse and hacker attacks***	2.60^cd (0.938)	2.56^cd (0.815)	1.79^ab (0.859)	1.91^ab (0.830)
Small farms will hardly be able to afford robots. Large farms will grow and small dairy farms will disappear***	1.95^bcd (0.813)	2.38^acd (0.828)	1.23^abd (0.437)	1.57^abc (0.641)
The use of robots can lead to even more standardization in livestock breeding and in the production of animal products***	2.58^bcd (0.798)	2.82^acd (0.726)	1.85^ab (0.812)	2.01^ab (0.774)
Factor 2: Opportunities on the societal level*** (F-value: 376.75)	− 0.18^cd	− 0.08^cd	1.02^abd	− 1.13^abc
Our domestic dairy farming becomes better with increasing progress in digital technologies in agriculture***	2.75^bcd (0.867)	3.26^acd (0.817)	4.22^abd (0.716)	2.42^abc (0.945)
Robotics will help us to solve problems in agriculture and dairy farming***	2.62^bcd (0.875)	3.09^acd (0.814)	3.96^abd (0.882)	2.21^abc (0.812)
I believe that the benefits of robots in dairy farming predominate***	2.42^bc (0.840)	3.22^acd (0.891)	4.10^abd (0.794)	2.36^bc (0.864)
The use of robots outweighs all negative aspects***	2.45 ^bc (0.804)	3.11^acd (0.856)	4.07^abd (0.808)	2.39^bc (0.925)
Robots help to bring farmers and consumers closer together***	3.12^bcd (0.982)	3.33^acd (0.706)	4.02^abd (0.811)	2.39^abc (0.966)
Using robots improves animal welfare because discrepancies in the cows' behavior are detected more quickly***	2.38^bcd (0.872)	3.22^acd (0.692)	3.66^abd (0.939)	2.14^abc (0.884)
Using robots leads to more transparency in dairy production***	2.54^bcd (0.909)	3.24^acd (0.693)	3.49^abd (0.955)	2.19^abc (0.838)
Factor 3: Opportunities for farmers*** (F-value: 426.23)	− 0.70^bcd	1.20^acd	− 0.27^ab	− 0.20^ab
Robots facilitate the everyday work routine of farmers***	1.46^bcd (0.551)	2.98^acd (0.712)	2.04^abd (0.761)	1.66^abc (0.626)
Robots help farmers increase their production***	1.81^bc (0.692)	3.03^acd (0.684)	2.13^abd (0.803)	1.84^bc (0.705)
Digitalization and robotics improve the quality of life of farming families***	1.74^bc (0.620)	3.07^acd (0.681)	2.58^abd (0.879)	1.90^bc (0.720)
Farmers can lower their costs in the long term by using robots***	1.82^bc (0.670)	3.15^acd (0.736)	2.68^abd (0.914)	1.98^bc (0.767)

Significance level at *p ≤ 0.05 **p ≤ 0.01 ***p ≤ 0.001; letters (a, b, c, d) indicate a significant difference to the corresponding cluster (Bonferroni post hoc test at significance level 0.05). The factor means are weighted scores based on the factor loadings shown in Table 2. The numbers not enclosed in brackets represent the mean values, while the numbers within brackets indicate the standard deviations of the items. Statements were scored with a scale from 1 = "fully agree" to 5 = "fully disagree". n = 1003

and cows is lost ($\mu = 1.55$; $\sigma = 0.766$) is a prominent finding here. In addition, these individuals reject the opportunities at the societal level. However, they agree with the advantages of digitalization for farmers, although with a slightly

Table 5 Socio-demographics and comparison of clusters with regard to further descriptive statements

	Proponents of robots (n = 292)	Indifferent citizens (n = 255)	Skeptical citizens (n = 273)	Critical supporters of robots (n = 183)
Gender*** (male/(female))[1] (%)	62 (38)[c]	50 (50)	40 (60)[a]	51 (49)
ø age (years)*	51[bd]	47[a]	50	46[a]
University degree[n.s. 1] (%)	25	10	11	16
Place of residence[n.s. 1] (urban/(rural)) (%)	59 (41)	69 (31)	59 (41)	62 (38)
Attitude dairy farming				
I believe that German dairy farming is important*** [2]	1.57[bc]	2.22[acd]	1.96[abd]	1.66[bc]
In general, I have a positive view of German dairy farming*** [2]	2.04[bc]	2.56[ad]	2.63[ad]	1.97[bc]
I trust in the work of German farmers***	2.06[bc]	3.60[ad]	2.58[ad]	1.95[bc]
Knowledge and connection to agriculture				
I am familiar with digital technologies in modern dairy farming***	4.27[d]	4.08	4.31[d]	4.31[ac]
I believe I have a high level of knowledge about dairy farming***	3.93[d]	3.98[d]	3.95[d]	3.58[abc]
I know about common agricultural practices in dairy farming**	3.56	2.78[d]	3.56	3.39[b]
I have friends, acquaintances, and/or relatives who work in agriculture*	3.74	3.82[d]	3.80	3.43[b]
Future expectations				
It is important to me that dairy products continue to get cheaper in the future***	3.49[bcd]	2.97[ac]	3.83[abd]	2.85[ac]
It is important to me that the dairy industry remains progressive and innovative in the future***	1.73[bc]	2.32[ad]	2.36[ad]	1.75[bc]
I would prefer it if dairy products were produced with less technology in the future***	3.46[bcd]	2.70[a]	2.51[a]	2.60[a]
The animal should be the main focus in dairy farming***	1.58[bc]	1.94[acd]	1.30[ab]	1.48[b]

Letters (a, b, c, d) demonstrate a significant difference to the corresponding cluster. Level of significance: $*p \leq 0.05$, $**p \leq 0.01$, $***p \leq 0.001$. [1]Chi-squared test according to Pearson. [2]These statements were scored with a scale from 1 = "fully agree" to 5 = "fully disagree". Bonferroni post hoc multiple comparisons tests at significance level 0.05. n = 1003

indifferent tendency regarding the improvement of the quality of life of farmers ($\mu = 2.58$; $\sigma = 0.879$) and long-term cost reductions through digitalization ($\mu = 2.68$; $\sigma = 0.914$). In this context, it is striking that the share of women is the largest (60%), while the share of men is the smallest. Furthermore, the proportion of rural residents is highest in both this cluster and in the cluster "proponents of robots". The "skeptical citizens" think dairy farming is important, but they are indifferent about their basic attitude toward German dairy farming and their trust in the work of German farmers. It is not important to the participants in this cluster that dairy products become cheaper; rather, the animal should be the focus of dairy farming. However, the dairy industry should remain progressive and innovative. Nevertheless, a rather skeptical opinion remains regarding the future use of technology.

The last cluster contains 183 citizens (18%) considered "**critical supporters of robots**" and represents the smallest cluster. Similar to the "skeptical citizens", the respondents agree with the risks of digitalization but show an even stronger agreement than the other clusters. Moreover, the assessments of the single items differ: respondents in this cluster mainly perceive the risk of unemployment in rural areas ($\mu = 1.98$; $\sigma = 0.798$) and that robots replace farmers ($\mu = 2.44$; $\sigma = 0.116$). In addition, the critical supporters of robots also strongly agree with the opportunities of robots, both for society and for farmers. However, agreement with the opportunities of robots for farmers predominates, as in cluster "proponents of robots", whereas the "critical supporters of robots" most clearly sees the opportunities to society, especially with regard to animal welfare ($\mu = 2.14$; $\sigma = 0.884$) and transparency of production ($\mu = 2.19$; $\sigma = 0.838$). The sociodemographic analysis shows that it is the youngest of the four clusters and has the second highest level of education. As the only one of the four clusters, it is important to the participants of this cluster that dairy products continue to become cheaper in the future. However, they also demand innovation and progress and focus on the animals in dairy farming. Their partly critical attitude toward digitalization is reflected in the slightly indifferent opinion on the future use of technology in milk production.

With regard to the acceptance by society, we considered all different dimensions of acceptance according to Schweizer-Ries et al. (2010) and Sauer et al. (2005) (see "Concept of societal acceptance in the research context" section and Appendix). The percentages of agreement are shown as a summary of the response options "fully agree" and "agree". The seven

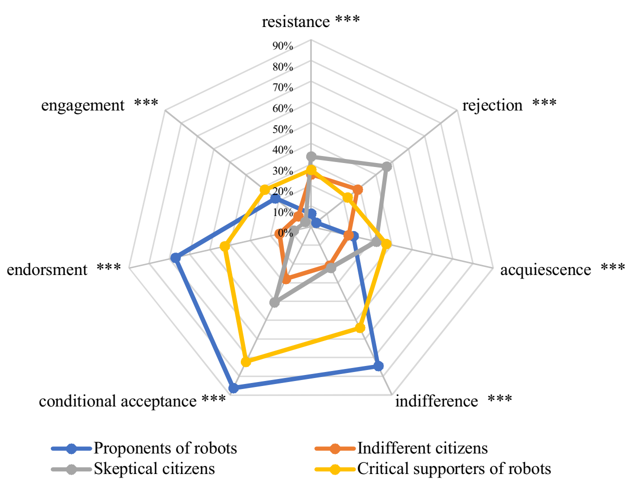

Fig. 2 Acceptance dimensions of societal acceptance ***p-values < 0.001 by Pearson's chi-squared test related to the mean values between clusters; percentage of agreement as sum of response options: fully agree and agree

different dimensions of acceptance are shown in the spider's web for each cluster and illustrate significant differences in acceptance among the four clusters.

First of all, it becomes clear that the action dimension of acceptance (active resistance or active acceptance) is given little consideration by society. In addition, it is noticeable that the evaluation is clearly more positive in clusters "proponents of robots" and "critical supporters of robots". In contrast, the "indifferent citizens" and the "skeptical citizens" do not show clear agreement and take a rather negative stance.

As expected, positive attitude acceptance predominates among the proponents of robots. They mainly (86.3%) place themselves in the area of conditional acceptance. However, indifference (74.6%) and endorsement (67.1%) are also dimensions of acceptance that the proponents of robots agrees with. The indifferent citizens do not clearly commit themselves to any of the forms of acceptance. Both conditional acceptance and rejection received approval ratings of just under 30%. Surprisingly, acquiescence and indifference as a form of acceptance did not receive high approval from this cluster. The cluster therefore does not appear to be indifferent to robots in dairy farming at all, even if the first impression of the cluster might suggest this (Fig. 2).

The skeptical citizens also reflect their skepticism toward robots in their attitude toward acceptance. On the one hand, they assign themselves to conditional acceptance (40.6%); on the other hand, an even stronger agreement to rejection can also be observed (46.5%). In addition, a third of the cluster even actively opposes robots in the dairy industry.

The attitudinal acceptance of the critical supporters is primarily classified as conditional acceptance (72.2%), indifference (54.1%), and advocacy (42.7%). However, a certain dichotomy can also be observed, indicating the critical view of the cluster. Thus, 37.1% of the participants in the cluster also agree with acquiescence (acceptance dimension with a negative tendency) as a form of acceptance.

Discussion

A variety of digital innovations have been established in the dairy sector over the past decade, and more technologies are likely to be added in the future to ensure sustainable dairy farming (Henchion et al. 2022). However, digital technologies have not yet become widely established in agriculture and dairy farming, and successful adoption on a broad scale is proving difficult. Different actors in agriculture perceive technologies differently, and these actors are in turn shaped by socially constructed beliefs, values and expectations about technologies and agriculture (Ibid.). Boogaard et al. (2011b, p. 1464) assume, specifically for dairy farming, that "(sociocultural) sustainable livestock development is socially and culturally constructed by people in specific contexts." In this study, different citizen segments were analyzed to gain deeper insights into the characteristics of proponents or critics of robots in dairy farming and to identify society's perceived risks and opportunities associated with these robots. To our knowledge, this study is the first to segment subjects based on their overarching attitudes toward relevant factors (perceived risks and opportunities) of adopting robotics in dairy farming.

First of all, our results show that societal acceptance refers predominantly to passive action. However, this finding is not surprising, as digital innovations and robots in agriculture have so far been given little social relevance, as they are often illustrated as abstract technologies whose concrete use and possible consequences for society remain obscure (Vierboom et al. 2006). Likewise, Devine-Wright (2008) assume that societal acceptance of technology is mostly purely attitudinal and thus often does not evoke active action. However, when innovative farming practices are rejected, it can result in a shift in purchasing habits such as opting for plant-based alternatives (Bruce and Bruce 2019).

The study also reveals that the use of robots is associated with both risks and opportunities. However, these attitudes are quite heterogeneous, which is in line with other studies, e.g., Millar et al. (2002), who showed that some citizens mainly see opportunities in milking robots, whereas others consider it problematic with regard to animal welfare. Overall, perceived opportunities of robots and the rejection of potential risks in this study lead to a high level of conditional acceptance and endorsement. This also confirms the assumption of de Groot et al. (2020) that attitude acceptance only occurs when more opportunities than risks are perceived. Surprisingly, the dimension of indifference also finds agreement even among proponents and critical supporters of robots, suggesting the presence of uncertainty within these groups.

Furthermore, the results demonstrate that although all four clusters acknowledge opportunities in robotics for farmers, these opportunities are not considered convincing enough to achieve full societal acceptance. However, the clusters do share the acknowledgment of the importance of the German dairy industry and concur on the necessity for it to maintain a progressive and innovative approach. This underscores a fundamental comprehension of the significance of advancement and technological progress within the dairy sector. Nevertheless, an apprehension associated with modernity is the concept of "instrumental rationality," as articulated by Taylor (1991), which pertains to a rationality solely focused on maximizing efficiency. This concern is particularly evident in the two critical clusters (skeptical citizens and critical supporters of robots) who express their malaise towards robot implementation through their endorsement of the associated risks. Moreover, the findings indicate a societal preference for prioritizing animal welfare in dairy production, emphasizing the need to prevent a dominant stance of digitalization in agriculture that neglects this aspect. Importantly, this viewpoint is not confined to the critical clusters alone, but is shared across all four clusters, underscoring the importance of upholding animal welfare as a means to enhance societal acceptance.

The recognition of both commonalities and divergences in perspectives regarding the use of robots among the clusters emphasizes the need for tailored strategies that can effectively address societal concerns. This insight is crucial for early consideration of concerns in the development and implementation of PLF technologies (Siegrist and Hartmann 2020).

The result that most individuals in the cluster that is characterized by lowest perceived risks ("proponents of robots") are men and highly educated is partially consistent with the findings of Pfeiffer et al. (2020), who found that men and higher educated have a more positive general attitude toward digitalization in agriculture. Bieberstein (2013) also discovered that men tend to perceive risks in food production to be lower than women. Furthermore, surprisingly, proponents of robots are the oldest cluster of this study. Concerning age, it is usually assumed in the digital context that younger people are more tech-savvy and generally more open to the use of technologies (Marescotti et al. 2021). However, this does not seem to apply to society's view of robots as the proponents of robots are the oldest participants and at the same time the least critical, also with regard to animal welfare concerns about digitalization. Different generations may have different values and priorities when it comes to agriculture and animal welfare. Older generations may prioritize efficiency and productivity, while animal welfare and sustainability are more important to younger generations (Fraser 2003; Vanhonacker et al. 2007). This difference in priorities could influence their attitudes toward the use of robots in dairy farming. This is line with findings by Boogaard et al. (2011a) who discovered that older people are more open-minded about modern production methods in milk production.

The "indifferent citizens" do not perceive any clear risks associated with the use of robots in agriculture, but neither do they perceive any opportunities. However, since this is necessary for the establishment of acceptance (Bredhal et al. 1998; Frewer 2017), the respondents in this cluster do not clearly assign themselves to any specific acceptance dimension. Their lack of trust in farmers' work could be a possible indication of the indecisiveness of the cluster because trust is considered to be of great importance in the process of societal acceptance (Ronteltap et al. 2007; Gupta et al. 2012; Siegrist and Hartmann 2020). If society trusts the actors responsible for the use of digital technologies, i.e., farmers, the acceptance of the use of the respective acceptance object is often more pronounced (Mohaupt et al. 2018). Especially when people know only little about a technology, acceptance may rely on trust in those using the technology (Huijts et al. 2012). As expected, all four clusters in this study estimate their knowledge of digital technologies in dairy production as rather low (Boogaard et al. 2010). The societal acceptance of digital innovations in agriculture may therefore also depend significantly on trust in the farmer, which was already demonstrated by Pfeiffer et al. (2020) and Sharp and Tucker (2005). Notably, the opportunities of digitalization at the societal level do not seem to be obvious to citizens, which is why they are apparently difficult for the public to evaluate. This finding goes hand in hand with the assumptions of Vierboom et al. (2006) and Siegrist (2008), who suggest that the advantages and disadvantages of technologies for society do not relate to everyday consumer life and that specific opportunities are therefore difficult or even impossible to recognize and evaluate.

In contrast to the indifferent citizens, the "skeptical citizens" agree with the opportunities of robots for farmers but reject the opportunities at the societal level. Furthermore, they have a high agreement with risks, especially in connection with the loss of naturalness, the contact between farmers and cows, and an advancing industrialization (small farms extinction) of agriculture through digitalization. Such risks, as a consequence of the interaction between farmer and technology, were also identified by Regan (2019) and Krampe et al. (2021). A look at the literature shows that women are more concerned about animal welfare than men (María 2006; Ruby 2012), and they particularly prefer naturalness and tradition in dairy farming (Boogaard et al. 2011a). Our results are consistent with these findings, as the proportion of women is highest in the cluster "skeptical citizens", and they consider it particularly important to focus on animals and animal welfare in dairy production.

Presumably, the strong emotional component associated with animal welfare, which also plays a role in the use of PLF technologies (Pfeiffer et al. 2020; Langer et al. 2022), could lead to the low conditional acceptance and the highest rejection of robots. Another reason for the lack of acceptance could also be that the opportunities of digitalization are only seen for the work of farmers but not for society as a whole (Millar et al. 2002; Pfeiffer et al. 2020). Indeed, it is generally assumed that acceptance is greater when the societal opportunities become concrete and tangible (Burgess 2010; Frewer 2017).

Society often represents contradictory expectations regarding ethical decisions in agriculture (Henchion et al. 2022). This is also evident in the cluster's expectations for future dairy farming: on the one hand, individuals value progress and innovation in dairy farming to foster modern and "safe" milk production; on the other hand, they want less technology to be used in dairy production in the future to maintain traditions and natural animal farming (Boogaard et al. 2010). This ambivalence suggests that this cluster believes that the use of technology and the achievement of naturalness and animal welfare are mutually exclusive (Krampe et al. 2021). The skeptical citizens should therefore be convinced that digital technologies not only offer opportunities to farmers but can also bring opportunities to animals and the environment, thus benefiting society as a whole.

The "critical supporters of robots" seem to be satisfied with digitalization as long as animals, traditions, and society are not threatened and everyone has opportunities from it (see also Boogaard et al. 2010). They support digitalization and appreciate modern achievements, such as cheap food, and expect that this will continue to be the case in the future. However, there is also a certain ambivalence in this cluster: progress and innovation are important to them, but they also wish to see a reduction in the use of technology in dairy production. Moreover, they agree with all the opportunities, both at the level of society (mainly with opportunities for animal welfare and transparency) and at the farmer level, but also with the potential risks of digitalization. Our findings confirm the results of Pfeiffer et al. (2020), who found that PLF technologies are seen as innovative and forward-looking by the majority of society, but at the same time, many negative attitudes prevail. When asked about the final attitude acceptance, it is striking that the ambivalent perception of the cluster is also reflected in a high degree of dichotomy and indifference. Nevertheless, the "critical supporters of robots" have an extremely positive attitude toward dairy farming and also have a high level of trust in the work of farmers. Since beliefs in society about the risks and opportunities of digitalization are embedded in more general attitudes (e.g., attitudes toward dairy farming or farmer per se) (Bredhal et al. 1998; Grunert et al. 2003; Ronteltap et al. 2007), this provides a possible approach to increase attitudinal acceptance. After all, the basic prerequisite for acceptance is clearly given in this cluster.

Conclusion and implication

The principle of responsible innovation should be the fundamental framework for the digital transformation of agriculture (Rose and Chilvers 2018). The RRI approach aligns research and innovation with societal values and needs, building trust and reflexivity among relevant actors (e.g. farmers, society, innovators, developers and policy). By adopting RRI, stakeholders can ensure that the development and use of robotic are not only accepted by producers, innovators, and farmers, but also aligned with broader societal values and needs and thus preventing beneficial innovations from being hindered by a lack of societal acceptance (Eastwood et al. 2019; Regan 2019). Our results provide initial insights into societal attitude acceptance and reveal differences in society (in the form of citizen segments), thereby contributing to the first indicator of the RRI approach.

None of the four clusters assigns itself exclusively to the negative evaluation dimensions. Nevertheless, varying concerns exist among the different clusters and ambivalent to negative acceptance attitudes are also adopted, mainly by the skeptical citizens. Thus, there is definitely a need for action to address societal concerns about an increasingly automated agriculture. The following section therefore presents strategies to address these concerns in the long term, which can also be integrated into the RRI approach.

In particular, the high proportion of undecided individuals regarding acceptance and the prevailing ambivalence which is evident in the clusters of indifferent and skeptical citizens, make it clear that citizens lack information and knowledge. The main concerns in these two clusters relate to cost, animal welfare and transparency. However, the cost problem can be effectively addressed, as the use of robots leads to cost savings in times of rising wage levels and a shortage of skilled workers in general (Harms and Bruhs 2018). To address animal welfare concerns, data generated from the use of robots should be utilized to integrate animal health data into current animal welfare labels and provide additional details on production conditions. So far, health data is not integrated into animal welfare labels because it is difficult to capture. Therefore, the implementation of robots offers the possibility to increase transparency when the data is used accordingly. Thus, especially the indifferent and critical citizens could be convinced that robots can indeed lead to more sustainability and transparency in dairy farming, with a steadfast focus on animal welfare.

Concerns about farm size and the loss of the farmer-animal relationship, expressed primarily by skeptical citizens and critical supporters of robots, are more complex. As noted by Busch et al. (2022), society uses farm size as the only indicator for evaluating sustainability and animal welfare because society lacks additional indicators. If additional criteria were created (e.g., production system, farmer attitude), this could likely also reduce societal concerns about the use of robots. However, this issue could pose a challenge for public communication across the sector (Ibid). Furthermore, it is known from other studies that information provision does not necessarily result in more acceptance (Wille et al. 2017; Sonntag et al. 2018). Society does not form or change attitudes based on knowledge and experience alone (Te Velde et al. 2002). For non-professionals in agriculture, the focus lies less on efficiency and more on the individual's value and moral conception (Enste et al. 2009; Boogaard et al. 2011b). Society tends to evaluate the use of PLF technologies ethically rather than from a technical or production cost perspective (Millar et al. 2002; Sonntag et al. 2018). Information and communication strategies about robots in dairy farming should therefore address fundamental values and include emotional components such as the opportunities to detect and improve the animals' health and welfare (Pfeiffer et al. 2020).

Furthermore, our results show that the societal opportunities associated with the use of robots are particularly relevant to the emergence of acceptance. The skeptical citizen cluster shows the lowest acceptance and at the same time the highest resistance to societal opportunities. It therefore seems particularly important to communicate and exploit the societal benefits more clearly, which in turn could encourage more farmers to adopt the technologies as this leads to greater societal appreciation. However, the various stakeholders in agriculture would hardly succeed in promoting societal acceptance through communication strategies alone (Sonntag et al. 2018). Hence, it is important to incorporate society's heterogeneous attitudes and perceptions about the risks and opportunities of robotics into the development of technologies from the very beginning.

In summary, this study can be interpreted as a meaningful survey as the results reveal a deeper and more nuanced understanding of the societal acceptance of two robots in dairy farming. They suggest that the digital transformation process in agriculture can be promoted if more emphasis is placed on the analysis of the public attitude and acceptance.

Limitations and further research

Since attitude acceptance is a complex phenomenon that can only become measurable through specific influence indicators, this study cannot fully make the construct of acceptance measurable. However, it has proven useful to reduce the focus to attitudinal acceptance and to make it measurable with the help of the acceptance dimensions according to Schweizer-Ries et al. (2010) and Sauer et al. (2005). Conventional acceptance models, such as those of Venkatesh et al. (2003), which assume an active intention to use, are inappropriate for this research context. For a more differentiated engagement with the concept of acceptance, the distinction between the acceptance subject, object, and context is unavoidable. However, factors that focus more clearly on context-bound spheres of influence should be included in further studies. This is because societal acceptance can vary depending on the social and cultural context (Schäfer and Keppler 2014). Examples of such influencing factors are norms and values, legal frameworks, political discussions, communication processes, or media backgrounds. Societal acceptance should also be placed in this context in further acceptance investigations to achieve an adequate analysis of the complex construct and thus also contribute further to the responsible innovation framework in precision and smart farming.

The present research has focused on identifying societal implications, contributing to only one aspect of the RRI approach. However, the other indicators of the approach should be applied in further research and RRI should be extended to the entire precision and smart livestock sector (Eastwood et al. 2019; Regan 2019). In addition, the consequences of the use of robots on animal welfare as well as on smaller farms should be investigated, since this is an important issue for sustainability reasons but also for communication with citizens and their acceptance. This demonstrates the importance of the all-encompassing approach of RRI.

Moreover, it should be noted that the terms "robots" (milking and feeding robots) and "digitalization" were used as generic terms and were not further defined or specified. Without a clear understanding of the specific technologies and processes being studied, it may be difficult to draw meaningful conclusions about their impact on society. However, the difference in the level of concreteness and tangibility between the items concerning risks and opportunities could potentially influence the acceptance of the respondents. In addition, the general conditions may vary depending on the technology and may be perceived differently. The societal acceptance of precision and smart farming can certainly not be generalized but should rather be considered individually for each technology and different production systems. Therefore, there is a need for further research, and additional technologies should be investigated in the societal acceptance discourse, e.g., field robots, which are still in the development process and have not (yet) found their way into practice.

Appendix

See Tables 6 and 7.

Table 6 Sources for the items of the object-related factors

Statements on the object-related factors	Source
Risks	
Using robots in dairy production no longer has anything to do with a natural production method	Boogaard et al. (2011a), Rose et al. (2021)
With robots, there is no personal interaction with the cows. The farmer becomes estranged from the animals	Herlin and Gunnarsson (2018), Pfeiffer et al. (2020)
The use of robots exacerbates the alienation of consumers and farmers	Driessen and Heutinck (2015), Pfeiffer et al. (2020)
By using robots, the farmer loses the opportunity to acquire knowledge through experience and observation	von Schönfeld et al. (2018)
The use of robots may negatively affect the overall sustainability of agriculture	Pfeiffer et al. (2020)
The use of robots increases the unemployment rate, particularly in rural areas	Störk-Biber et al. (2020), Krampe et al. (2021), Rose et al. (2021);
By buying a robot, farmers become very dependent on the digital infrastructure and its supply	van der Burg et al. (2019)
Robots replace the work of the farmer; sooner or later the farmer's job will no longer be important	Block and Long (2016)
Digital systems are susceptible to data misuse and hacker attacks	Krampe et al. (2021)
Small farms will hardly be able to afford robots. Large farms will grow and small dairy farms will disappear	Herlin and Gunnarsson (2018)
The use of robots can lead to even more standardization in livestock breeding and in the production of animal products	Short (1992), Block and Long (2016), Pfeiffer et al. (2020)
Opportunities on the societal level	
Our domestic dairy farming becomes better with increasing progress in digital technologies in agriculture	Wolfert et al. (2017), Shepherd et al. (2018)
Robotics will help us to solve problems in agriculture and dairy farming	Störk-Biber et al. (2020)
I believe that the benefits of robots in dairy farming predominate	Störk-Biber et al. (2020)
The use of robots outweighs all negative aspects	Wolfert et al. (2017), Shepherd et al. (2018)
Robots help to bring farmers and consumers closer together	Pfeiffer et al. (2020)
Using robots improves animal welfare because discrepancies in the cows' behavior are detected more quickly	Schukat and Heise (2021)
Using robots leads to more transparency in dairy production	Frewer et al. (2011), Krampe et al. (2021)
Opportunities for farmers	
Robots facilitate the everyday work routine of farmers	Schukat and Heise (2021)
Robots facilitate the everyday work routine of farmers	Bitkom (2020), Sheperd et al. (2018)
Robots help farmers increase their production	Stuart et al. (2012), Regan (2019), Bitkom (2020)
Digitalization and robotics improve the quality of life of farming families	Bitkom (2020)

Table 7 Items acceptance dimension according to Sauer et al. (2005)

Acceptance dimension	Item	Fully agree				Fully disagree
Resistance	I stand up against the use of robots in dairy farming	1	2	3	4	5
Rejection	I categorically reject the use of digital robots in dairy farming	1	2	3	4	5
Acquiescence	I am torn about the use of digital robots in dairy farming	1	2	3	4	5
Indifference	I am neither for nor against the use of digital robots	1	2	3	4	5
Conditional acceptance	I accept the use of robots in dairy farming under certain conditions	1	2	3	4	5
Endorsement	I support the use of robots in dairy farming	1	2	3	4	5
Engagement	I advocate the use of robots in dairy farming	1	2	3	4	5

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Declarations

Conflict of interest The authors declare no competing interests.

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Greta Langer is a PhD student at the Department of Agricultural Economics and Rural Development in the "Marketing for Food and Agricultural Products" working group. She holds an M.Sc. in Agricultural Sciences with specialization in Agribusiness Management from the University of Goettingen. Her current research focuses on digital transformation in the dairy industry, with an emphasis on social acceptance of digitization and readiness to use digital technologies within agriculture.

Sarah Kühl studied business administration at Leuphana University of Lüneburg (Germany) and then worked in sales. This was followed by a master's degree in equine science and a doctorate on the topic of "Differentiation strategies based on agricultural production processes in the food market" at the Chair of Marketing for Food and Agricultural Products, University of Göttingen (Germany). Following the PhD, she took up a position as a research assistant at the Chair of Livestock Sciences at the Free University of Bolzano (Italy) and conducted, i.a., economic analyses of livestock farms. After working as a strategic consultant, she returned to the Chair of Marketing for Food at the University of Göttingen as a postdoc and is working on consumer behavior in organic and animal welfare products as well as local and digital marketing of food.