Public acceptance of Robots and Autonomous Crop Farming – A cluster analysis of German citizens' attitudes and concerns

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Abstract.
Public acceptance is essential for technology innovation in agriculture. Due to the recent advances in artificial intelligence, robotics and autonomous systems (RAS) could soon revolutionize crop farming landscapes. What is society's view on crops being produced with the help of autonomous machines and how do different groups accept the technologies? A sample of 567 German citizens was segmented into clusters using an unsupervised machine-learning technique. The analysis elaborated on heterogeneity in public attitudes concerning challenges and advances of RAS. A majority of the participants are in favor of the use of RAS. While 41% of the participants positioned themselves as positive (Proponents), about 19% of the sampled participants even showed a strong positive attitude towards RAS use in crop farming (Enthusiasts). Nevertheless, of the participants, 29% support RAS use overall but raise concerns regarding socio-economic impacts of RAS (Skeptical Proponents), and 11% (Skeptics) take a skeptical stance. Skeptical Proponents and Skeptics fear negative consequences for family farms and are doubtful about potential positive environmental contributions. The ease of farm work and environmental benefits drive RAS acceptance among Proponents and Enthusiasts. Potential concerns among critical citizens, as revealed in this study, should be recognized and addressed by the farming sector on the development path to more automated agriculture. The advantages of the technologies need to be articulated through targeted scientific communication. The change toward automation can hardly be prevented in any area of life, but food production is a comprehensive and sensitive topic affecting everyone, which should be considered in communication efforts. The advantages of the technologies need to be articulated through targeted scientific communication.

Keywords.
Autonomous crop farming, Responsible Research and Innovation, Public acceptance, PAM clustering

Introduction

The idea of a driverless tractor is over 80 years old when Frank W. Andrew invented 1940 a cable steered tractor (Condon, 1940). However, only the rapid development of GPS technology and, in particular, artificial intelligence in recent years is turning the idea of automated fieldwork into reality (Jha et al., 2019). Currently, a variety of robotics and autonomous systems (RAS) is under development (Gil et al., 2023). However, even with technologies showing great success in fieldwork, like combined sowing and hoeing machines for organic farming, RAS are still a niche product (Gerhards et al., 2023). Nevertheless, the demand for RAS will grow with refined technologies (Sparrow & Howard, 2021), leading to a profound change of crop farming systems. Examining society's perspective on this development is recommendable to address public obstacles early in order to let RAS unfold its potential to fulfilling society's aspirations for more sustainable agricultural systems (Walter et al., 2017). In the future, laypersons will increasingly interact with RAS. For example, while walking in recreational areas or traveling along roads and routes, an important contrast compared to autonomous farming machines used in premises or barns, such as milking robots or breeding technologies and digital solutions invisible to laypersons.

The Responsible Research and Innovation (RRI) framework of the European Union seeks to include the perspectives of all stakeholders affected by innovations (Eastwood et al., 2019). Nevertheless, social perspectives often fall short in innovation processes (Henchion et al., 2022). Research on agricultural robots focuses on technical and economic feasibility as well as environmental benefits (Ditzler and Driessen, 2022; Gil et al., 2023; Feisthauer et al., 2023). However, food systems are complex and a sensitive public issue (Lusk et al., 2014). Public perceptions of agricultural systems and food production might change when fieldwork is increasingly automated. Assessing the public perspective is crucial at an early stage of innovation, as it allows developers to adapt technologies to meet social requirements (Eastwood et al., 2019).

Social opinions are diverse. Hence, it can be assumed that heterogeneous perspectives on RAS exist (Smith, 1956). Therefore, this paper segments German citizens' perceptions regarding the potential benefits and hurdles of RAS to address this heterogeneity and detect differences in acceptance. In an online survey, three examples of RAS technology applications in crop farming were presented: a spot-spraying robot, a fertilizer-spreading drone, and an autonomous tractor tilling the field, creating the notion of an autonomous crop farming system. Each example was illustrated using image materials and explanatory texts to enhance understanding.

In the remainder of the paper, we first discuss the theory of public acceptance concerning technology innovation processes and summarize current research investigating public acceptance of automation and digitization in farming systems. We subsequently explain the framework of challenges for autonomous farming used here to investigate technology acceptance. The paper focuses on the results of the segmentation approach using partitioning around medoids (PAM) unsupervised machine-learning technique.

Research background

The concept of social acceptance in the context of technological innovations

Understanding technology acceptance is a pivotal component for the successful implementation of technologies (Upham et al., 2015) and for addressing potential concerns early through communication approaches. Social acceptance research has a long tradition in food innovation processes, and its importance is widely recognized (Lusk et al., 2014). In the diffusion theory of innovation, social acceptance gains importance in the persuasion and decision stages (Rogers, 1995). However, contemporary social acceptance research extends its focus to earlier stages of technology development to align developmental processes with social requirements and legal frameworks (Upham et al., 2015).

Acceptance is a complex concept. A rich field of literature exists examining user acceptance of technology. Technology acceptance models examine, for example, the usefulness and ease of use of technologies deriving users' attitudes (Venkatesh et al., 2003). By focusing on the user perspective, technology acceptance models fall short of describing the broader concept of social acceptance. According to Wüstenhagen et al. (2007), acceptance involves multi-dimensional, dynamic processes categorized into three domains: social, community, and market acceptance. Although Wüstenhagen et al. (2007) originally investigated acceptance within the realm of renewable energy, this classification of acceptance can be extended to the acceptance of agricultural production patterns, already shown for the acceptance of biogas, a technology on the edge of renewable energies and agricultural production patterns (Emmann et al., 2013). Despite differences in the permanence and intensity of landscape impacts, parallels exist between the technologies. Consumers of both final products, electricity, and food, do not directly use the producing technologies but interact indirectly with the technologies impacting landscapes. In addition, renewable energies and autonomous agricultural systems might fundamentally change the central supply industries of energy and food.

The present study focuses on the domain of social acceptance. Individual opinions towards the automation of crop farming systems were surveyed. The analysis explores the influence of sociodemographic characteristics to determine heterogeneity in individuals' acceptance (Gupta et al., 2012). Furthermore, following acceptance research on animal welfare, the rural/urban divide and trust in farmers were included as acceptance determinants (Vanhonacker et al., 2007).

Public acceptance of digitalized and automated farming

The findings on the public acceptance of RAS in crop farming are based on current literature, as the first commercial robot applications just reached market readiness in recent years (Gil et al., 2023). In general, a supportive attitude can be deduced from these studies in different countries (Wilmes et al., 2022; Pfeiffer et al., 2021; Spykman et al., 2022; Wu et al., 2023). Positive environmental aspects associated with the technologies appear to be valuable arguments for acceptance. Wilmes et al. (2022) found that digital agriculture is associated with environmental benefits in the context of organic farming. In addition, hedonistic reasons, such as reducing pesticide residues in food, also promoted acceptance in the mentioned study. Environmental benefits were also drivers of acceptance in a study conducted among Chinese food consumers concerning autonomous drone use in agriculture (Wu et al., 2023). Additionally, the mass media, as the main information source for general society, positively discussed environmental benefits when reporting on precision farming (Mohr and Höhler, 2023). Pfeiffer et al. (2021) noted a certain openness to subsidizing farming robots in German society. However, RAS raised the potential for controversies in this study, as the affective reactions to presented RAS technologies caused mixed reactions concerning varying machine sizes.

Literature investigating the advantages and disadvantages of RAS discussed further potentially controversial socio-ethical impacts of RAS use in agriculture. One concern is the uncontrolled utilization of data by machine manufacturers- a potential power factor within the food chain (van der Burg et al., 2021). The data collected could also touch third-party rights unrelated to the conducted task or even unrelated to farming at all (Bergstrom et al., 2022; Yoo et al., 2018). Additionally, the infrastructure required for these technologies may be vulnerable to cyberattacks, increasing the risk of an unstable food supply (van der Burg et al., 2021). Moreover, the implementation of RAS has the potential to jeopardize jobs in agriculture, leading to demographic decline in rural areas and fostering structural changes towards larger farm structures, further impacting the rural socio-economic landscape (Zscheischler et al., 2022; Sparrow & Howard, 2021; Eastwood et al., 2019).

Challenges to responsible research and innovation through public lenses

RRI aims to align innovation with society's social and ethical values (Eastwood et al., 2019). It emphasizes on innovators and regulating bodies having responsibilities that are beyond technical productivity and safety of products. Hence, socio-ethical questions and impact assessments for stakeholders, society, and the environment play a critical role concerning technological innovations.

Eastwood et al. (2019) utilized the RRI framework to analyze digital innovations in the dairy sector. In this process, seven major challenges in the dairy sector were identified that could be addressed with the help of digital and autonomous technologies: *Community acceptance and connection, Economics and viability*, *Environment*, *Attracting and retaining skilled people*, *Lifestyle and business*, *Animal welfare*, and *Technology performance and infrastructure*. While animal welfare is crucial in livestock farming, it does not apply to the case of RAS in crop farming. However, the six other challenges can be applied analogously to the presented RAS. These topics cover the RRI approach in an application-oriented manner. The social perspective is covered in the *Community Acceptance and Connection* section and is evaluated in the study context from an individual social acceptance perspective. However, it is interesting to explore perceptions of non-agricultural society beyond acceptance for research purposes.

For this reason, the challenges were adapted to a perspective compatible with societal aspirations on modern farming systems to elaborate heterogeneity in public perspectives. The framework serves not only to elaborate heterogeneity based on the challenges potentially addressed by RAS use in crop farming but also on potential hurdles and negative effects of RAS use extracted from literature. Figure 1 shows the application of the different challenges according to the social perspective. The challenges have been adapted to reflect non-agricultural laypersons' views and were centered on RAS use. For example, the *Economics and viability* challenge was adapted to a broader food security perspective.

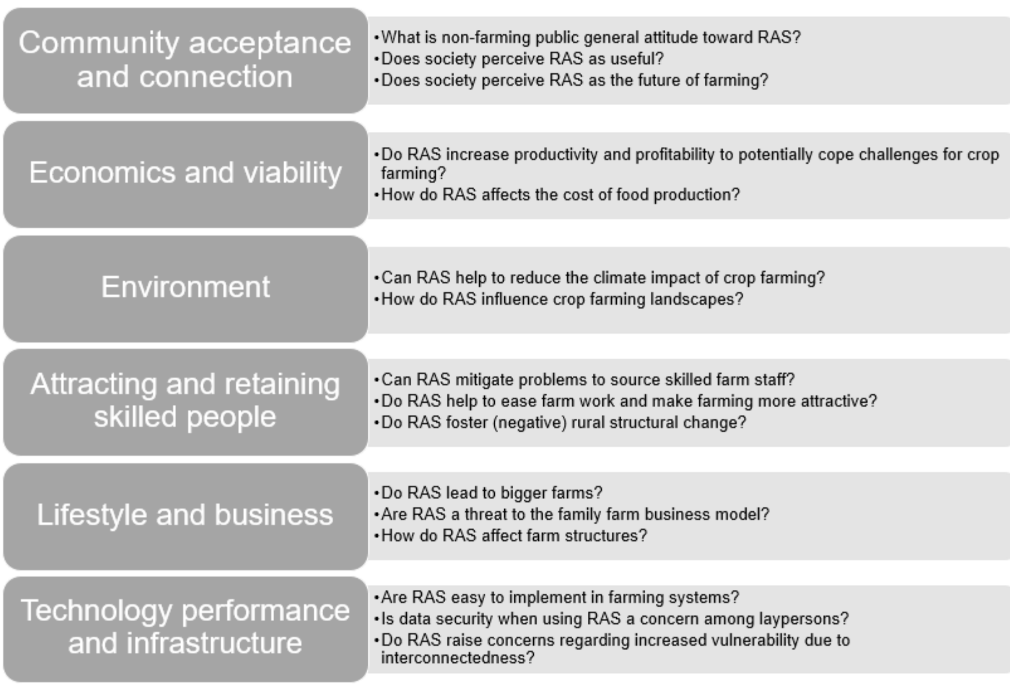

Figure 1 Challenges for RAS (own illustration based on (Eastwood et al., 2019))

Material and methods

Study design and data collection

Data collection took place in January 2023. Quota sampling was used to collect a representative sample of German citizens concerning important sociodemographic characteristics. A professional panel provider handled the recruitment of the participants. The study design was tested two times. In November 2022, 27 participants were interviewed to determine whether the presented information on RAS were understood. In December 2022, a soft launch was conducted with the panel provider (n=248). Following a strict data-cleaning process, speeders (response time 50% less than the median of 13.5 minutes) and straightliners (participants who showed no variation in response behavior despite answering contradictory questions) were removed. After data cleaning, the data set comprised 569 participants. For the analysis presented here, two additional participants were excluded due to missing data, resulting in a final data set of 567 participants.

Subsequently, the survey procedure for the variables relevant to this study is described: The participants were randomly assigned to either the control group or one of the treatment groups of the original study, receiving additional positive information about RAS. This study exclusively analyzes participants in the control group, who received only general information about the illustrated RAS technologies.

The general information comprised three images of RAS technologies: an autonomous tractor robot tilling the soil, a spot-spraying robot, and a fertilizer-spreading drone. The operation of the machines was explained, and a conventional non-robotic counterpart was presented as an image comparison (tractor with tillage machine mounted, sprayer attached, and fertilizer spreader mounted). It was pointed out that the robots and the drone work autonomously once the user has programmed them. The participants could listen to the explanation as an audio file or read the text while scrolling through the images. The technology description and the images are available in a separate file via the appendix link.

Before the information section, the sociodemographic characteristics of the participants were collected. The description of the machines was followed by questions regarding the acceptance of the machines, possible advantages and disadvantages of the technologies.

In the final part of the survey, participants were asked to rank nine agricultural topics addressed in the study, which are potentially influenced by RAS technology, on a preference scale from 1 to 9. A rank of 1 indicated the highest priority, while a rank of 9 indicated the lowest priority. The nine topics were: 1. healthy food (minimizing residue in food), 2. sustainable farming (ensuring resources for future generations), 3. environmentally friendly farming, 4. food availability; 5. affordable food, 6. family farming (preservation of family-owned farms), 7. socially friendly farming (socially acceptable agricultural practices), 8. preservation of a human component in farming systems, and 9. data security in food production.

Sociodemographic data were collected using nominal and ordinal scaled questions. Unless otherwise indicated, the questions were asked on a five-point Likert-type scale from 1= "Strongly disagree" to 5= "Strongly agree" with a neutral mid-point.

Statistical analysis

The data was analyzed using the statistical software R (Version 4.2.0).

Descriptive statistics

Descriptive analysis was conducted to describe the sociodemographic characteristics of the sample and to ensure that the characteristics align with those of the German society.

The variables were selected to align with the respective RRI challenge as one construct. The formed constructs were checked in terms of validity using the average variance extracted (AVE), McDonald's Omega, and Cronbach's alpha. Cut-off criteria were set according to the literature at 50% for AVE and 0.6 for McDonald's Omega and Cronbach's alpha (Hair, 2009). Minimal deviations below the criteria were tolerated as the data is exploratory. To ensure directional loadings statements were re-coded for construct formation, if necessary, for the construct formation.

After the cluster segmentation, as a final step of the descriptive analysis, the clusters were compared based on significant differences in response behavior and sociodemographic differences. Since the variables were subject to different distribution patterns, Kruskal-Wallis tests were used to detect group differences. If the Kruskal-Wallis result was significant, a Dunn post hoc test was performed using Benyamini-Hochberg correction to determine which cluster comparison revealed significant differences.

Partitioning around medoids

A cluster analysis was carried out based on the construct average scores extracted from RRI challenges for RAS use.

The clustering method chosen was the partitioning around medoids (PAM) method. In contrast to the more popular clustering method of k-means clustering, which can, however, only analyze continuous quantitative data, PAM can process mixed data, both quantitative and qualitative (Botyarov & Miller, 2022). Furthermore, PAM minimizes the dissimilarities of all observations to the nearest medoid. In this process, PAM selects points as data centers and can handle arbitrary distances. Compared to other cluster methods like K-means, the cluster's center is not necessarily on a data point of the input data. Therefore, the point selection process as a data center increases the robustness against outliers (Lesmeister, 2015).

Before the PAM clustering process, the dissimilarity between the individual observations was calculated. The calculation resulted in a distance matrix. Euclidean Distance method was used to compute this matrix (Eq. 1) (Botyarov & Miller, 2022).

$$d_{euc}(x, y) = \sqrt{\sum_{i=1}^{n}(x_i - y_i)^2} \quad (1)$$

PAM optimizes the formation of clusters based on the distance matrix and the number of k groups considered.

Given X being a set of n points (in this case, the participants) in a p-dimensional space the method obtains an optimal set $M \subset X$ consisting of k points called medoids $M = \{x_{m1}, \ldots, x_{mk}\}$ taken from X (Domingo et al., 2023). Each observation is assigned to the closest medoid, followed by a swapping process between each medoid and non-medoid observation. In this process, the dissimilarity costs are computed (Lesmeister 2015). The process concludes with the selection of the minimal total dissimilarity as a solution described in equation 2 (Domingo et al. 2023):

$$TD = \sum_{i=1}^{n} d_{euc}(x_{i,} x_m) \quad (2)$$

The assignment to the closest medoid and the detection of the minimal dissimilarity run until the machine detects no change in the medoid (Lesmeister, 2015).

Optimal number of clusters

The number of extracted clusters set by the authors critically affect the outcome of cluster method studies. To objectify this process computational methods were used to facilitate choices (Lesmeister, 2015).

The R package "NbCluster" computes 23 methods to determine the optimal cluster number. A minimum cluster solution of two clusters and a maximum solution of eight was specified in this process. The 23 methods were calculated using the Euclidean distance method to correspond to the selected dissimilarity analysis in the PAM algorithm (Eq. 1). Of these 23 ways; nine methods proposed an optimal result of four clusters, seven methods an optimal result of two, four methods proposed an optimal number of three clusters, two methods signaled an optimal solution of eight clusters while one method proposed a seven-cluster-solution. According to the majority rule, a four-cluster solution was selected.

Additionally, the Elbow Criterium method, a common graphical solution based on the within-cluster sum of squares to identify the best number of clusters, was analyzed. The Elbow Criterium method suggested likewise a four-cluster solution.

Results

Sample description

Table 1 shows the sample description presenting the selected sociodemographic variables.

Table 1 Sample distribution of age, sex, education, income, and place of residence in reference to the German population

Variable	Sample n=567	Germany (Reference)
Age		
18-29	101 (17.8%)	18%
30-39	92 (16.2%)	17%
40-49	88 (15.5%)	16%
50-59	132 (23.3%)	21%
>60	154 (72.2%)	28%
Sex		
Male	281 (49.6%)	50%
Female	286 (50.4%)	50%
Divers	-	n.a.
Education		
No qualification/SNVQ[1]	185 (32.6%)	31%
Secondary school VQ[2]	177 (31.2%)	32%
High school (Abitur)	205 (36.2%)	36%
Income		
<1,500 €	91 (16.1%)	13%
1,501-3,000 €	190 (33.5%)	33%
3,001-4,500 €	172 (30.3%)	31%
>4,501 €	114 (20.1%)	23%
Residence		
City	425 (75.0%)	77%
Village	142 (25.0%)	23%

Total numbers of respondents, share of respondents per category in parenthesis; [1]SNVQ= Secondary school non-vocational qualification, Corresponds to the German "Hauptschulabschluss"; [2]VQ= Vocational Qualification, Corresponds to the German "Realschulabschluss"

The average age of the respondents is 48.6 years. 49.6% of the participants are male and 50.4% female. Overall, 36% of respondents claim to hold a high school diploma (German= Abitur). Secondary school is reported by 63% as the highest level of schooling. These participants are divided into 31.2% with a vocational qualification (German Realschulabschluss) and 31.9% with a non-vocational qualification (German Hauptschulabschluss). Four participants, corresponding to 0.7%, have no school qualification. In accordance with the German census, 16.1% of the participants live in households with a net monthly income of less than €1,500 per month. 33.5% have €1,501-3,000 at their disposal, and 30.4% between €3,001 and €4,500 (20.1% above €4.500). One-fifth of the participants belong to households with a net income of more than €4,500 per month. The largest group of respondents originates from west Germany (36.4%), followed by southern Germany (28.1%), eastern Germany (18.6%), and northern Germany (18.6%). Three-quarters of participants live in cities, which is representative of Germany (World Bank, 2023).

Cluster description

Table 2 presents the average response results per cluster to the respective constructs and the according inference calculations regarding significant group differences. The exact wording of the statements and the construct validation values are available in Table 1 of the file attached under the appendix link. Table 3 displays the cluster describing sociodemographic characteristics and the average topic preference per cluster. In addition, Table 3 also presents the results of the statistical inference calculation between the groups regarding differences in characteristics and topic preferences.

Table 2 Average cluster responses to potential advantages and concerns regarding RAS

Item (Nomenclature as in Table 3)	Cluster A Skeptics n=61 (10.8%)	Cluster B Skeptical proponents n=164 (28.9%)	Cluster C Proponents n=236 (41.6%)	Cluster D Enthusiasts n=106 (18.7%)	Total sample
Community acceptance	2.56^{bcd}	3.59^{acd}	4.29^{abd}	4.84^{abc}	4.01
Attitude	*2.46^{bcd}*	*3.47^{acd}*	*4.23^{abd}*	*4.79^{abc}*	*3.93*
*Strongly & Rather disagree**	*n=29 (47.6%)*	*n=7 (4.2%)*	*n=0*	*n=0*	*n=36 (6.3%)*
Partly/Partly	*n=24 (39.3%)*	*n=78 (47.6%)*	*n=17 (7.2%)*	*n=2 (1.9%)*	*n=121 (21.3%)*
*Rather & Strongly agree**	*n=8 (13.1%)*	*n=79 (48.2%)*	*n=219 (92.8%)*	*n=104 (98.1)*	*n=410 (72.3%)*
Future	2.49^{bcd}	3.60^{acd}	4.22^{abd}	4.78^{abc}	3.96
Usefulness	2.74^{bcd}	3.69^{acd}	4.31^{abd}	4.87^{abc}	4.07
Willingness to purchase	2.54^{bcd}	3.62^{acd}	4.40^{abd}	4.93^{abc}	4.07
Economics and viability	2.14^{bcd}	2.92^{acd}	3.27^{abd}	3.77^{abc}	3.14
Food security	2.64^{bcd}	3.59^{acd}	3.92^{abd}	4.49^{abc}	3.80
Food quality	2.62^{bcd}	3.31^{acd}	3.74^{abd}	4.39^{abc}	3.62
Future without robots$^{(-)}$	4.20^{bcd}	3.47^{acd}	3.27^{abd}	2.88^{abc}	3.35
Costly$^{(-)}$	4.53^{bcd}	3.77^{acd}	3.31^{abd}	2.93^{abc}	3.50
Environment	2.56^{bcd}	3.40^{acd}	3.89^{abd}	4.39^{abc}	3.70
Climate friendly	2.64^{bcd}	3.38^{acd}	3.90^{abd}	4.37^{abc}	3.70
Biodiversity	2.38^{bcd}	3.17^{acd}	3.67^{abd}	4.25^{abc}	3.49
Preservation of soils	2.61^{bcd}	3.51^{acd}	3.98^{abd}	4.41^{abc}	3.78
Ecosystem protection	2.66^{bcd}	3.44^{acd}	3.98^{abd}	4.43^{abc}	3.77
Environmental protection	2.51^{bcd}	3.51^{acd}	3.93^{abd}	4.52^{abc}	3.76
Attract. & retain. people	2.59^{bcd}	3.20^{acd}	3.62^{abd}	4.31^{abc}	3.52
Workload reduction	3.46^{bcd}	3.98^{acd}	4.49^{abd}	4.81^{abc}	4.29
Leisure time	3.33^{bcd}	3.81^{acd}	3.99^{abd}	4.52^{abc}	3.97
Jobs in agriculture	1.90^{bcd}	2.54^{acd}	2.91^{abd}	3.83^{abc}	2.87
Job losses$^{(-)}$	4.33^{bcd}	3.52^{acd}	2.91^{abd}	1.93^{abc}	3.06
Lifestyle and business	4.30^{bcd}	3.32^{acd}	2.64^{abd}	2.09^{abc}	2.91
Alienation$^{(-)}$	1.82^{bcd}	2.75^{acd}	3.36^{abd}	3.83^{abc}	3.11
Farms	1.90^{bcd}	3.00^{acd}	3.67^{abd}	4.16^{abc}	3.38
Family farms$^{(-)}$	4.62^{bcd}	3.71^{acd}	2.94^{abd}	2.27^{abc}	3.22
Technology per. & infrastr.	3.95^{bcd}	3.00^{acd}	2.47^{abd}	1.89^{abc}	2.68
Cyber security	1.98^{bcd}	2.55^{acd}	2.99^{abd}	3.54^{abc}	2.86
Data security	2.10^{bcd}	3.00^{acd}	3.49^{abd}	4.16^{abc}	3.32
Production systems$^{(-)}$	3.87^{bcd}	2.83^{acd}	2.36^{abd}	1.88^{abc}	2.57
Research	2.00^{bcd}	3.27^{acd}	3.99^{abd}	4.61^{abc}	3.68

Values that are not labeled differently represent mean values; Factor score means are measured after re-coding of negative polarized items; *Two categories on the original scale that are summarized; a= Significant difference between the respective cluster and cluster a on the basis of p=0.05 and respectively for ^{bcd} (inference based on a significant Kruskal-Wallis test and group-wise comparisons with the Dunn post-hoc test); all items are measured on a five-point Likert type scale: 1= Totally disagree, 2= Disagree, 3= Partly/Partly, 4= Agree, 5= Totally agree; (-)= Item with negative polarization (inverted Likert type scale).

The formed clusters are characterized as follows:

Cluster A is formed by the *Skeptics*. At 10.8% sample share, this group forms the smallest cluster. In terms of attitudinal acceptance, the *Skeptics* are either unsure whether RAS should be used in crop farming (39%) or tend to reject RAS use (48%) (Table 2).
Regarding the potential impact of RAS, the *Skeptics* perceive risks for family farms and expect

jobs in agriculture to potentially be jeopardized. Data security issues also raise concerns in this group, as well as rising food prices due to more expensive farming technologies. The *Skeptics* ascribe little potential to the technologies regarding more environmentally friendly agriculture and general usefulness in agriculture. In addition, they firmly reject investments in research of RAS.
Nevertheless, the potential ease of farm work is perceived as a positive contribution. The topic preference ranking (Table 3) confirms the response behavior of the *Skeptics* toward RAS. Maintaining a certain human involvement in food production is weighted significantly higher by the *Skeptics* than by participants of the other clusters. Furthermore, the family farm as a guiding principle holds great importance. In contrast, environmentally friendly and sustainable farming are less important. Affordable food also ranks number seven, lower than in the other three clusters.
The *Skeptics* average age is slightly higher concerning the other clusters (Table 3). Furthermore, the education and income levels are slightly lower. Compared to the *Proponents* and *Enthusiasts*, the low proportion of city dwellers (about 62%) and the high proportion of women (about 67%) are statistically significant. In addition, trust in local farmers is the lowest among participants in this cluster.

Cluster B represents the *Skeptical Proponents*. The *Skeptical Proponents* are either undecided about whether RAS presented should be used in crop farming (48%) or rather agree that the technologies should be used (44%). With just under 29% sample share, this cluster is the second largest.
The *Skeptical Proponents*' reservations about RAS are similar to those of the *Skeptics*, albeit at a lower level. Concerns about higher food prices, job losses, and uncertainty concerning family farm preservation are prevalent. In addition, the increased vulnerability of food systems due to RAS is perceived as a potential threat. The *Skeptical Proponents* continue to attach importance to the family farm, albeit less weighted than by the *Skeptics*. Environmentally friendly agriculture ranks high in third place. However, RAS are not necessarily perceived as a solution for more environmentally friendly farming. The *Skeptical Proponents* are undecided or only slightly optimistic whether RAS contribute to environmentally friendly farming, particularly regarding improved biodiversity. Furthermore, the *Skeptical Proponents* are the only cluster ranking food availability as the second most important topic. As with all clusters, healthy food is ranked with the highest priority. The reduction in workload for farmers is rated as an advantage of RAS by *Skeptical Proponents*, and integration into existing agricultural systems is perceived as relatively simple.
The *Skeptical Proponents*, like the *Skeptics* comprise significantly more female than male participants. At the same time education ranks between higher (*Proponents*) and lower educated (*Skeptics*) clusters. The average age is the youngest among the clusters, and the household income is significantly lower compared to the *Proponents, who have* the highest average income. Like the *Skeptics*, the *Skeptical Proponents* trust domestic farmers significantly lower compared to the *Proponents* and *Enthusiasts*. In addition, the proportion of city dwellers (69.5%) among the *Skeptical Proponents* is higher than for the *Skeptics* but significantly lower than among *Proponents* and *Enthusiasts*.

The *Proponents* form the largest cluster (Cluster C), with a sample share of 41.6%. The *Proponents* agree that RAS should be used in crop farming (93%) and feel positive about RAS contribution to agricultural systems in terms of usefulness and especially about ease of farm work. Furthermore, they perceive the potential for food security and environmental improvements in farming systems from RAS. Essential factors concerning farming systems for the *Proponents* are sustainability for future generations, ranking second, and environmentally friendly farming, ranking third. Interestingly, food affordability is more important to the *Proponents* compared to the *Skeptics* and *Skeptical Proponents*, while the share of humans in production is not as highly ranked as in the previous clusters. The potential rise of food prices due to expensive technologies is not seen as a major concern by the *Proponents*, and the role of family farms is not as important to them as to the *Skeptics* and *Skeptical Proponents*. Concurrently, the *Proponents* do not perceive the family farms threatened due to RAS. An uncertain evaluation exists among the *Proponents* regarding vulnerability due to potential cyber-attacks on RAS. Nevertheless, like for

the *Skeptics* and *Skeptical Proponents*, data security in farming systems is the least prioritized topic in the ranking.
The respondents in the *Proponents* cluster are characterized by an average age close to the sample average. The same applies to the proportion of city dwellers (about 78%) and trust in local farmers. However, compared to the *Skeptics* and *Skeptical Proponents*, the share of city dwellers and trust in farmers are significantly higher. The *Proponents* mark, on average, the cluster with the highest education level (insignificant compared to the other clusters) and the highest net household income (significant compared to clusters *Skeptics* and *Skeptical Proponents*). Remarkably is a high share of men (about 56%) and city dwellers (about 78%) compared to the *Skeptics* and *Skeptical Proponents*.

The respondents forming cluster D are the *Enthusiasts* (about 19% of the sample share). All but two undecided study participants in this cluster support using RAS in crop farming.
The *Enthusiasts* rank the surveyed topics in the same manner as the *Proponents*. The human share is even lower in priority, ranking at nine. The *Enthusiasts* are highly willing to pay for food produced by RAS and perceive high potential for environmental benefits. Rising food prices and RAS endangering family farms are not rated as concerns. Unlike the other three clusters, the *Enthusiasts* doubt that future farming systems will be economically viable without using RAS and claim to intensify research in technologies like the presented RAS. Furthermore, they are the only group to rate the chance for employment in agriculture using RAS more positively than negatively. *Enthusiasts* are marked by the highest share of men (58%), city dwellers (83%), and the highest trust in farmers. They also represent the second oldest group. Regarding education and net household income, the respondents rank on average among the *Proponents*.

Table 3 Cluster describing sociodemographic variables, trust in farmers, and average topic ranking by cluster

	Cluster A Skeptics n=61 (10.8%)	Cluster B Skeptical proponents n=164 (28.9%)	Cluster C Proponents n=236 (41.6%)	Cluster D Enthusiasts n=106 (18.7%)	Total sample n=567
Group characteristics					
Average age	53.57	47.27	47.73	49.71	48.59
Share of women in %	67.21%^{cd}	58.54%^{cd}	44.07%^{ab}	42.44%^{ab}	49.56%
Average education[1]	2.82	2.98	3.10	3.08	3.03
Average income[2]	2.33^{c}	2.34^{c}	2.70^{ab}	2.63	2.55
Share of city dwellers in %	62.30%^{cd}	69.51%^{d}	78.39%^{a}	83.02%^{ab}	74.96%
Trust in farmers	2.99^{cd}	3.14^{cd}	3.32^{ab}	3.50^{ab}	3.27
Topic (Participants ranked the topics according to their importance, from 1=most important to 9= least important)					
Healthy food	3.56/1	3.46/1	3.08/1	3.37/1	3.30
Sustainable farming (for future generations)	4.84^{d}/4	4.60^{d}/4	3.98/2	3.73^{ab}/2	4.21
Environmentally friendly farming	5.23^{cd}/6	4.41/3	4.10^{c}/3	3.81^{d}/3	4.26
Food availability	5.15/5	4.30/2	4.29/4	4.31/4	4.39
Affordable food	5.34/7	5.07/6	4.67/5	5.08/5	4.94
Family farming	4.30^{c}/2	4.84/5	5.32^{a}/6	5.22/6	5.05
Socially friendly farming	5.41/8	5.82/8	5.85/7	5.22/6	5.68
Human component	4.41^{bcd}/3	5.74^{acd}/7	6.60^{acd}/8	7.17^{abc}/9	6.22
Data security	6.77/9	6.74/9	7.10/9	7.10/8	6.96

Values that are not labeled differently represent mean values; ^{a}= Significant difference between the respective cluster and cluster a on the basis of p=0.05 and respectively for ^{bcd} (inference based on a significant Kruskal-Wallis test and group-wise comparisons with the Dunn post-hoc test); education and income were measured according to the categories in Table 1; trust was measured on a five-point Likert type scale: 1= Very low, 2= low, 3= I am not sure 4= High, 5= Very high and is an average score out of three questions (1. Trust regarding environmental protection, 2. Trust regarding animal welfare, 3. Trust regarding food quality).

Discussion

Using unsupervised machine-learning, we elaborated heterogeneity in society's perspective towards RAS. The overall results confirm society's overarching positive assessment of automation in agriculture found in earlier studies (Pfeiffer et al., 2021; Wilmes et al., 2022).

However, an in-depth analysis of participants' perceptions regarding RAS's potential societal benefits and issues reveals diverse opinions. It confirms the chosen study approach to extend the investigation beyond the attitudinal acceptance evaluation. Especially the skeptical clusters provide important insights, as in the past, critical voices often carried considerable weight in evaluating new food-producing technologies (Lusk et al., 2014).

Potential environmental benefits and reduced farmers' workload are perceived benefits of RAS across clusters. While socio-ethical issues are mostly important to the general public, for farmers, economic efficiency caused by technological hurdles is decisive (Gil et al., 2023). Nevertheless, overlaps between societal expectations and adoption factors among farmers exist regarding control over the technology, perceived social norms influencing adoption, and environmental benefits (Mohr & Kühl, 2021; Feisthauer, et al. 2023).

Besides economic viability and perceived control of technologies used, attracting and retaining people is substantial for farmers (Redhead et al., 2015). The working environment is an important issue in this context. An overlap exists between the participant's perspective that the RAS eases crop farm work and the farmer's perspective, as Rübcke von Veltheim et al. (2022) detected the potential ease of farm work as one of the major performance factors for successful adoption of RAS. Based on this, unlike the other clusters *Enthusiasts* even expect new employment chances for workers in the agricultural sector due to RAS, which is also discussed for robot use in non-agricultural sectors (Damelang & Otto, 2023).

Nevertheless, the *Skeptics* and *Skeptical Proponents* perceive a certain risk of agricultural workers becoming unemployed due to increased RAS use. One possible explanation for the higher concern among the *Skeptics* and *Skeptical Proponents* is the higher share of rural dwellers. Therefore, closer contact with workers employed in agriculture is likely, potentially increasing the adoption of farm workers' perspectives. Considering public concerns, it is vital in an RRI process to communicate future employment opportunities and the ease of farm work as benefits of the technologies. However, further research should also focus on jobs at risk in agriculture due to automation and on possible consequences for rural areas, farm workers, and further education.

While potential job losses for agricultural workers are a concern among the *Skeptics* and *Skeptical Proponents*, but rather not for the supportive citizens, the guiding principle of the family farm receives considerable weight from a large share of participants. Policy regulation also sets the preservation of family farms as a goal (European Commission, 2024). For the *Skeptics* and *Skeptical Proponents*, the potential displacement of the family farm due to RAS use is a strong determinant for critically evaluating RAS.

Against this context, it is important to note that the definition of a family farm comprises a family worker's share and the transfer of ownership, land tenure, or management to the next generation. Nevertheless, substantial structural differences exist between individual family farms in terms of size (van Vliet et al., 2015). The family farm might serve as a proxy for reducing socially complex issues, as Busch et al. (2022) noted for farm sizes. Therefore, it remains inconclusive which structural attributes of the family farm are important to the participants. Future research needs to investigate how RAS potentially jeopardizes family farm structures.

Following on from the perception of RAS impacting farm structures, societal perspectives on farm operation due to the shift towards RAS might change and potentially drive the societal aspiration for human-centered family farms. Regardless of a small or large structure, automated farms operate differently from what laypersons are familiar with. In an increased RAS scenario, the farmer no longer operates in the field (Blok & Long, 2016). Therefore, research has to determine whether the model of the family-owned farm needs to be preserved or whether models of production methods are also associated with it. Here, heterogeneity exists. For the *Skeptics*, the human component of production is a major determinant, while for the *Proponents* and *Enthusiasts*, the human component is of low preference.

The *Skeptics*' desire to maintain a human component in production is contextualized by the negative assessment of the potential economic contribution of RAS in terms of food security and supply. One logical explanation would be that *Skeptics* trust humans more than RAS to decide, for example, whether crops are ripe and which diseases need to be controlled. However, this explanation contradicts the low level of trust in domestic farmers among the *Skeptics*. Rather, the findings of this study are in line with other studies determining trust in farmers as an acceptance factor for autonomous farming (Langer & Kühl, 2023; Pfeiffer et al., 2021). The other clusters assess the economic potential of RAS as overall positive. Interestingly, all clusters except the *Enthusiasts* can imagine that farmers can be able to farm successfully without RAS in the future. Here, the social consensus and farmers' skepticism regarding RAS's economic viability overlap (Redhead et al., 2015).

The general skepticism detected towards RAS could also drive *Skeptics* and *Skeptical Proponents* concerns regarding data and cyber security issues potentially arising from automated farm machinery. Studies suggest that data regulation should be adjusted (Zscheischler et al., 2022; van der Burg et al., 2021). Farmers potentially have to disclose much of their valuable data to machine manufacturers (van der Burg et al., 2021). For society, the question of the vulnerability of food systems through interconnected machines is of relevance. This is reflected in the response behavior of all clusters except for the *Enthusiasts*. Another critical issue that needs to be examined in further research is the perceived public risk of information gathered that might surpass the intended scope of RAS usage, as privacy concerns were strong predictors for consumers' intentions to use drone delivery services (Yoo et al., 2018). The uncertainty in data regulation may explain why the *Proponents* are also quite critical when assessing data and cyber security issues. Even if the topic is less important to the study participants than other topics, the study results reveal a legitimate social interest regarding data regulation. Therefore, data security for agricultural robots requires protection not only for users but also for those who interact indirectly with the technology.

In addition to addressing data security concerns, the environmental advantages serve as a compelling rationale for recommending the adoption of RAS (Sparrow & Howard, 2021). Similarly, farmers share this perspective - although farmers may not necessarily understand their contribution to be the extensification of farming and the use of RAS does not per se promote the idea of sustainability (Feisthauer et al., 2023). The broad media advertises automated and digital farming technologies as potential contributors to more sustainable farming (Mohr & Höhler, 2023). This sustainability potential is a strong driver for accepting RAS in society. The potential is not only reflected in the response behavior of *Proponents* and *Enthusiasts* but was also confirmed by previous studies (Wilmes et al., 2022; Pfeiffer et al., 2021).

However, not all clusters exhibit this positive attitude towards the environmental benefits of RAS. In particular, the two more skeptical clusters, which are recruited to a greater extent from rural areas, are less convinced of the environmental potential of RAS. One explanation for this could be that the skeptical clusters generally attach less importance to environmental issues. Another reason could be a certain realism due to the greater proximity of the rural population to agriculture. RAS can certainly contribute to more sustainable agriculture (Ditzler & Driessen, 2022). However, automation alone will not achieve sustainable farming as society desires. Other technologies like genetic engineering (Qaim, 2020) and behavioral changes in land use and consumption are likewise required (Arneth et al., 2017; Parlasca & Qaim, 2022).

Although the literature suggests no greater acceptance of modern agricultural systems among the rural population compared to city dwellers (Gabriel & Gandorfer, 2021), further research could investigate whether society perceives RAS as an addition or substitute to critical technologies like genetic engineering rejected by parts of society (Qaim, 2020) with a special focus on whether differences in the assessment between rural and urban dwellers occur.

In addition to exploring participants' perceptions on farming challenges that could be addressed

RAS and the resulting socio-ethical considerations, sociodemographic differences between the clusters were analyzed. Interestingly, only the proportion of urban dwellers, as already discussed, and the proportion of women provide significant differences among clusters. Women appear to be more critical toward RAS than men, as the share of women in the *Skeptical Proponents* and *Skeptics* clusters is significantly higher. This gender gap in acceptance can also be found in Langer & Kühl (2023) regarding milking robots. Possible reasons for this are a lower risk awareness in food production among men compared to women (Bieberstein, 2014) and a higher preference for naturalness and traditional farming methods (Boogaard et al., 2011). However, a generally higher level of interest in autonomous technologies among men could also be an influencing factor, as research from social robots suggests (Xu, 2019).

Conclusion

The idea of RAS has been with farmers for decades. The recent advances in artificial intelligence bring this vision closer to becoming a reality. Therefore, understanding the drivers and barriers to the acceptance of autonomous agricultural systems in society is paramount. A focus on the acceptance of end products alone is not enough. RRI should be a guiding principle for the transformation of agriculture towards more automation.

Overall, using RAS in crop farming receives broad public support. Overlap exists regarding the evaluation of challenges and opportunities perceived by agriculture and farmers. The analysis presented herein revealed heterogeneity among the analyzed participant's opinions. None of the four clusters assesses the use of RAS in crop farming solely in negative dimensions. Ease of farm work is acknowledged among all clusters, and positive environmental effects are highly valued among supporters of RAS. Nevertheless, concerns or ambivalent assessments were found among the *Skeptical Proponents* and *Skeptics*, which account for 40% of the sample. *Skeptical Proponents* and *Skeptics* do not perceive strong environmental benefits through RAS use. Critical factors for technology acceptance are the preservation of family farms and, in line with this, the labor market consequences and potential structural changes in agriculture through RAS use. Moreover, critical participants place importance on the human component retained in the production process during RAS-operated fieldwork, contrasting with those more supportive of RAS. Further, transparent data protection rules might be important for gaining acceptance.

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Appendix

For reasons of space, the images of the machines used and the descriptions of the technologies are available under the following link. The same applies to Appendix Table 1, which lists the specific statement formulations and the construct validity parameters. https://uni-bonn.sciebo.de/s/rRD16yTXqhpeLkX