German Journal of Agricultural Economics Vol. 74 (2025), 1-28

Original Research Article

https://doi.org/10.52825/gjae.v74i.2283

Submitted: 09 Aug. 2024 | Accepted: 07 Feb. 2025 | Published: 31 Mar. 2025

Public Acceptance of Robots and Autonomous Crop Farming – A Cluster Analysis of German Citizens' Attitudes and Concerns

Hendrik Hilmar Zeddies[1,*] and Gesa Busch[2]

[1]Center for Development Research (ZEF), University of Bonn, Germany

[2]University of Applied Sciences Weihenstephan-Triesdorf, Germany

*Correspondence: Hendrik Hilmar Zeddies, hzeddies@uni-bonn.de

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 and investigated political attitudes in relation to RAS attitudes. 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% even showed a strong positive attitude towards RAS use (Enthusiasts). The ease of farm work and environmental benefits drive RAS acceptance among Proponents and Enthusiasts. Nevertheless, 29% support RAS use overall but raise concerns regarding socio-economic impacts (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. A higher share of right-wing and non-voter participants is detected among the more skeptical clusters, while green (environmental) party voters are among the more positive participants. Potential concerns should be recognized and addressed by the farming sector on the development path to more automated agriculture. Food production is a sensitive topic affecting everyone, which should be considered in communication efforts. The advantages of RAS technologies need to be articulated through targeted scientific communication.

Keywords: Autonomous Crop Farming, Responsible Research and Innovation, Public Acceptance, PAM Clustering

1 Introduction

The idea of a driverless tractor is over 80 years old, as Frank W. Andrew invented 1940 a cable steered tractor (Condon, 1940). However, only the development of GPS technology and, in particular, artificial intelligence in recent years is turning the idea of automated fieldwork into reality. Currently, various robotics and autonomous systems (RAS) are 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 niche products (Gerhards et al., 2023). Nevertheless, the demand for RAS will grow with refined technologies, leading to a profound change in crop farming systems.

Farmer's willingness to adopt RAS is the most important criterion for successful upscaling. Nevertheless, examining society's perspective on this development is recommendable to let RAS unfold its potential to fulfill society's aspirations for more sustainable agricultural systems (Sparrow, Howard, 2021). RAS do not alter food products directly but potentially reshape farming practices, and thus, affect public perceptions of sustainability and technological advancements in agriculture (Pfeiffer et al., 2021) while directly affecting employment in agriculture when fieldwork is increasingly automated (Sparrow, Howard, 2021). Public perceptions of agricultural systems have implications that extend beyond the food product itself, with topics such as farm sizes and landscape management sparking controversy and influencing policy decisions (Kupidura et al., 2014; van Vliet et al., 2015; Busch et al. 2022). Assessing the public perception at an early stage of innovation allows developers to adapt technologies to meet societal requirements, aligning with the European Union's Responsible Research and Innovation (RRI) framework, which emphasizes including all stakeholder perspectives in the development process (Eastwood et al., 2019).

Social opinions are usually diverse. Hence, heterogeneous perspectives on RAS might exist (Smith, 1956). Therefore, this paper aims to draw on different public perceptions (in the form of citizen segments) of RAS concerning perceived benefits and hurdles and a socioeconomic description of the identified segments. The citizen segment responses regarding the underlying preferences for agricultural systems extend the description of the clusters. Additionally, this article investigates relationships between participants' political preferences and RAS attitudes. Agricultural policy has been the subject of intense debate in recent years among farmers and within society (Saleh et al., 2024). Political parties have different visions of the future direction of agricultural policy (AfD, 2021; Bündnis90/Die Grünen, 2021; CDU, 2021; FDP, 2021; SPD, 2021). For this reason, it is insightful to examine whether associations exist between political opinions and public perspectives on RAS.

The results of this study contribute to developing potential solutions and strategies to enhance societal acceptance of robots in crop production. Neither the underlying preferences for agricultural systems nor political preferences have been analyzed in the context of RAS perceptions – to the best of our knowledge. Previous literature on the acceptance of RAS in crop farming has focused on the overall social context (Wu et al., 2023; Wilmes et al., 2022; Pfeiffer et al., 2021), or on the consumption decisions of food produced with RAS (Spykman et al., 2022).

The data used in this study was drawn from a larger investigation into German society's awareness of crop farming robots and the impact of positive framing on acceptance (Zeddies et al., 2024). The overall study design included an experimental approach, where participants were randomly assigned to groups that received different types of positive framing. The framing approach hinders an unbiased segmentation of different social perspectives for the whole sample. Therefore, the present article is confined to analyzing the control group subsample, comprised of 567 participants who received a neutral description of the technologies' functioning without any positive framing information. We applied a cluster analysis technique to segment the participants.

2 Research Background

A comprehensive understanding of the public acceptance of technological innovation in agriculture requires an initial review of the theoretical foundations of acceptance research and relevant literature.

Understanding technology acceptance is pivotal for successfully implementing technologies and addressing potential concerns early through communication approaches (Upham et al., 2015; Archer et al., 2008).

This study investigates public acceptance by focusing on individual, predominantly non-user perspectives regarding the automation of crop farming systems. Hence, theories of user acceptance research, like technology acceptance models, fall short of describing the broader concept of public acceptance (Venkatesh et al., 2003).

Wüstenhagen et al. (2007) highlight the significance of individual (social) acceptance as a critical component of the multi-dimensional and dynamic process of acceptance as they categorize acceptance into three distinct domains: social acceptance, which comprises the public/individual perspective, community acceptance, 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 methods, already shown for the acceptance of biogas, a technology on the edge of renewable energies and agricultural production (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 technologies that produce them but interact indirectly with the technologies that affect landscapes.

The remainder of this chapter reviews relevant literature concerning the public acceptance of agricultural innovation and concludes by defining the study's segmentation framework.

2.1 Public Acceptance of Digitalized and Automated Farming – Literature Review

The findings on 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 (Wu et al., 2023; Wilmes et al., 2022; Pfeiffer et al., 2021). With a focus on the direct consumption decision on products from precision agriculture, Spykman et al. (2022) segmented German consumer's attitudes towards crop farming robots, focusing on the degree of autonomy and different weed control methods. The weeding method was perceived as more important than the degree of autonomy, with environmental benefits being highly valued by consumers. Wilmes et al. (2022) also 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, promoted acceptance. 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, mass media positively discussed environmental benefits when reporting on precision farming (Mohr, 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 presented RAS technologies caused mixed affective reactions concerning machine sizes.

Controversial socio-ethical impacts of RAS use in agriculture are also discussed in the literature. 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 displace 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 (Sparrow, Howard, 2021; Eastwood et al., 2019).

2.2 Challenges to Responsible Research and Innovation Through Public Lenses

The previous chapter outlined the theories underlying public acceptance of technological innovations in agriculture and the current state of research. This chapter presents the theoretical framework for the sample segmentation conducted in this study, tailoring the Responsible Research and Innovation approach (RRI) for RAS in crop farming to the perspectives of public acceptance.

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 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 might be applied analogously to the presented RAS. These topics cover the RRI approach in an application-oriented manner.

The original concept by Eastwood et al. (2019) focused on stakeholder perspectives, with the social dimension addressed in the *Community Acceptance* section. As the six challenges extracted, including the *Community Acceptance*, are relevant not only for stakeholders but also for society, we investigate these challenges from a public acceptance perspective. The six challenges are conceptualized as a set of constructs.

Constructs can be defined as theoretical foundations measured through multiple indicators, most often in confirmatory research (Jacobucci, 2022). However, this study follows an explanatory approach due to the absence of a standardized framework for measuring attitudes and concerns associated with RAS. Hence, the underlying data is observational. The theoretical rationale for categorizing the items into constructs is based on the framework of Eastwood et al. (2019) and is informed by previous research within the field of public acceptance.

The construct *Community acceptance* is measured as attitudinal acceptance based on the affective component of the ABC model of attitude (Solomon, 2006). The *Economics and viability* construct is focused on potentials and concerns regarding RAS use mentioned by Sparrow, Howard (2021) and Wu et al. (2023). Environmental benefits are the main driver of RAS promotion in German media (Mohr, Höhler, 2023), but also extracted by several studies as a driver of acceptance (e.g., Wu et al., 2023; Wilmes et al., 2022; Pfeiffer et al., 2021). While Pfeiffer et al. (2021) and Spykman et al. (2022) examined public perceptions regarding on-farm employment changes through RAS use (*Attracting and retaining skilled people)*, these studies, along with Langer et al. (2023), also explored perceptions of broader changes in farming structure and systems resulting from the use of RAS (*Lifestyle and business*). The *Technology performance and infrastructure* construct refers to infrastructure risks related to data collection by RAS technology (Bergstrom et al., 2022; van der Burg et al., 2021). It also explores public opinion on investments in RAS research to improve RAS technology, with findings from Pfeiffer et al. (2021) indicating that most respondents support these initiatives.

Figure 1 shows the application of the different challenges according to the public perspective. The challenges have been adapted to reflect non-agricultural laypersons' views and were centered on RAS use. The original challenges extracted by Eastwood et al. (2019) are attached in the Appendix (Appendix Figure A1).

Construct	Underlying Research Questions	Construct Items
Community acceptance and connection	•What is the general attitude of the non-farming public toward RAS? •Does society perceive RAS as useful? •Does society perceive RAS as the future of farming?	1. Should robots like the ones you have seen before be used in agriculture? 2. I believe that the use of robot machines is the future of agriculture. 3. Robots could be of great benefit to agriculture. 4. I would buy food produced with the help of robots.
Economics and viability	•Do RAS increase productivity and profitability to potentially cope with challenges for crop farming? •How do RAS affect the cost of food production?	1. Secured food supply* 2. Enhanced food quality* 3. I believe that farmers will be able to produce economically profitable in the future without digital technologies such as robots. 4. As robots are expensive, food prices could eventually also rise.
Environment	•Can RAS help to reduce the climate impact of crop farming? •How do RAS influence crop farming landscapes?	1. Climate friendly food production* 2. Enhanced biodiversity* 3. Ecosystem protection* 4. Enhanced environmental protection*
Attracting and retaining skilled people	•Can RAS mitigate problems by sourcing skilled farm staff? •Do RAS help to ease farm work and make farming more attractive? •Do RAS foster (negative) rural structural change?	1. Reducing the workload on farms* 2. More leisure time for farmers* 3. Jobs in agriculture* 4. I believe that farmers could lose their jobs in agriculture due to the widespread use of robots.
Lifestyle and business	•Do RAS lead to bigger farms? •Are RAS a threat to the family farm business model? •How do RAS affect farm structures?	1. I rate the risk of society becoming more alienated from food production through the use of agricultural robots as low. 2. I believe that all types of agricultural farms could profit from robots in agriculture. 3. Robot technology increases the risk that the family-run farm in Germany will become extinct.
Technology performance and infrastructure	•Are RAS easy to implement in farming systems? •Is data security when using RAS a concern among laypersons? •Do RAS raise concerns regarding increased vulnerability due to interconnectedness?	1. I rate the risk of agricultural robots being potential targets for hacker attacks and cybercrime as low. 2. Data collection by agricultural robots gives me little cause for concern. 3. I believe that it is difficult to integrate robots into existing production systems in agriculture. 4. We should intensify research on agricultural robots and invest in this field.

Figure 1. Challenges for RAS cluster constructs and underlying items

Source: own illustration based on Eastwood et al. (2019) *Based on the question: how do you estimate the influence of the use of robots in agriculture on the following areas?

3 Material and Methods

3.1 Study Design and Data Collection

Data collection took place online 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 participants. The study was reviewed and approved by the Ethics Committee of the Center for Development Research (University of Bonn). The study design was pre-tested two times. In November 2022, 27 participants were interviewed to determine whether the presented information on RAS were easy to understand. In December 2022, a soft launch was conducted with the panel provider (n = 248) prior to the full launch.

In the study, participants were randomly assigned to either the control group or one of the three treatment groups, receiving additional positive information about RAS. The results of the treatment experiment can be found in Zeddies et al. (2024). This study focuses exclusively on participants in the control group, who received only a general description of the presented technologies. Using the entire sample might have introduced bias, as the framing experiment produced varying effects among participants. As a result, the segmented groups would not have been comparable due to different information they were given. The control group, however, remains unaffected by a framing bias, as participants were only given a general description of the technologies. Both the English translation of the description and the German original are attached in the Appendix. While the general description was necessary to inform participants about the function of the technologies, care was taken to use a neutral tone to minimize potential bias in shaping their opinions.

A strict data-cleaning process was embedded for the full-sample, and 58 participants were discarded from the control group. 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 of 567 participants.

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, also using an image (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 attached in the Appendix.

Before the information section, the sociodemographic characteristics of the participants were collected. The description of the machines was followed by questions/statements regarding the acceptance of the machines and possible advantages and disadvantages of the technologies. These questions/statements encompass the variables for the cluster framework in Figure 1.

After having seen the information, 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 food residues), 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. As the last survey question, participants were asked to select a party from the German party spectrum or respective declare indecisiveness or being a non-voter. For this purpose, a fictitious scenario of national elections on the day of the survey was created.

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.

3.2 Statistical Analysis

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

3.2.1 Descriptive Statistics

The six formed constructs were checked in terms of validity using McDonald’s Omega, Cronbach’s alpha and Guttmann´s Lambda-2. Cut-off criteria were set at 0.6 (Hair, 2009). We tolerated minimal deviations from the criteria as the data is exploratory. To ensure directional loadings, statements were re-coded for construct formation, if necessary.

After the cluster segmentation (see methodology description in next paragraph), the clusters were compared regarding their construct’s response behavior and sociodemographic differences. In addition to the characteristics of gender, age, education, and income, the influence of the rural/urban divide, trust in farmers, and relationship to farming were examined, drawing on insights from animal welfare acceptance research (Vanhonacker et al., 2007).

Since the variables were subject to different distribution patterns, Kruskal-Wallis tests were used to detect group differences. If the Kruskal-Wallis result was statistically significant, a Dunn post hoc test was performed using Benyamini-Hochberg correction to determine statistically significant differences between the clusters. The nominally scaled variable party preference was tested for statistically significant differences between the clusters using a chi-square test.

3.2.2 Partitioning Around Medoids

A cluster analysis was carried out on the construct-level using the construct average scores extracted from RRI challenges for RAS use (Figure 1).

To form the clusters, we used the partitioning around medoids (PAM) method. In contrast to the more popular clustering method of k-means, which can, however, only analyze continuous quantitative data, PAM can process mixed data, both quantitative and qualitative (Botyarov, Miller, 2022). 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 selection process 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).

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

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 $M = \{x_{m1}, \dots, x_{mk}\}$ 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 calculation concludes with the selection of the minimal total dissimilarity as a solution described in Equation 2 (Domingo et al. 2023):

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

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

The robustness of the results was verified by conducting a K-means cluster analysis that confirmed the general conclusions of the PAM approach (Appendix Table A2).

3.2.3 Optimal Number of Clusters

The number of extracted clusters set by the researchers critically affects 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. We specified a minimum of two clusters and a maximum of eight clusters. The 23 methods used the Euclidean distance method to correspond to the selected dissimilarity analysis in the PAM algorithm. 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.

The Elbow Criterium was also used as a common graphical solution based on the within-cluster sum of squares to identify the best number of clusters. The Elbow Criterium method suggested a four-cluster solution likewise (Appendix Figure A2).

4 Results

4.1 Sample Description

Table 1 shows the sample description presenting 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)[1]
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[2]	185 (32.6%)	31%
Secondary school VQ[3]	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]Source: “b4p - Best for planning 2023” (long-term market media study program in Germany analyzing media use and consumer behavior since 2013.); [2]SNVQ = Secondary school non-vocational qualification, Corresponds to the German “Hauptschulabschluss”**;** [3]VQ = Vocational Qualification, Corresponds to the German “Realschulabschluss”; n-a. = not available
Source: own calculation

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).

4.2 Cluster Description

Figure 2 represents the attitudinal acceptance of the presented technologies in the clusters. Table 2 presents the average responses per cluster to the constructs and the according inference calculations regarding statistically significant group differences. The construct *Attracting, retaining skilled people* marginally violates the reliability criterium for Cronbach's Alpha and Guttmann's Lambda-2, but since McDonald's omega exceeds the acceptable level, it is retained in the analysis. Table 3 displays the cluster describing sociodemographic characteristics, and Figure 3 illustrates differences in agricultural topic preferences between the clusters. A further description of the shown follows in the description per cluster.

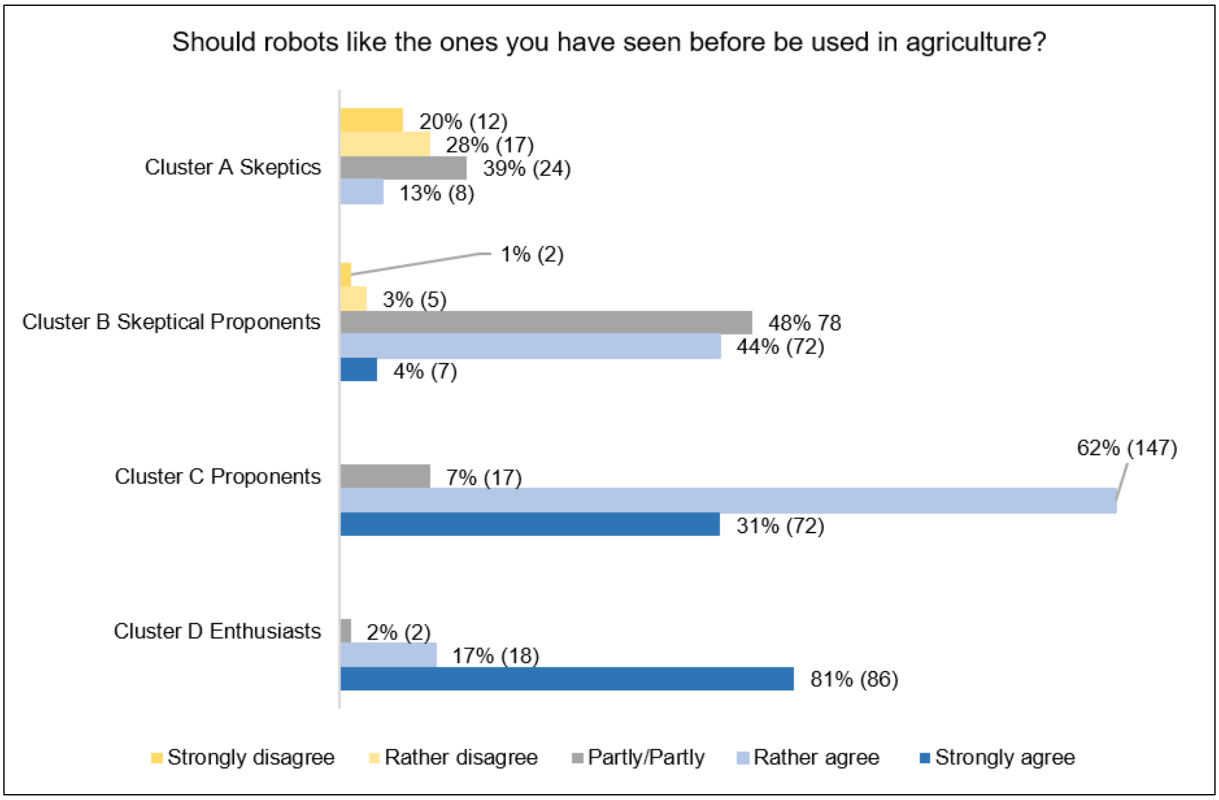

Figure 2. Attitudinal acceptance toward presented technologies per cluster

Source: own calculation and illustration

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

Item	**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
Community acceptance (McDonalds ω: 0.89; Cronbach's α: 0.89; λ-2: 0.89)	2.56[bcd]	3.59[acd]	4.29[abd]	4.84[abc]	4.01
Should robots like the ones you have seen before be used in agriculture?	2.46[bcd]	3.47[acd]	4.23[abd]	4.79[abc]	3.93
I believe that the use of robot machines is the future of agriculture.	2.49[bcd]	3.60[acd]	4.22[abd]	4.78[abc]	3.96
Robots could be of great benefit to agriculture.	2.74[bcd]	3.69[acd]	4.31[abd]	4.87[abc]	4.07
I would buy food produced with the help of robots.	2.54[bcd]	3.62[acd]	4.40[abd]	4.93[abc]	4.07
Economics and viability (McDonalds ω: 0.65; Cronbach's α: 0.60; λ-2: 0.60)	2.14[bcd]	2.92[acd]	3.27[abd]	3.77[abc]	3.14
Secured food supply*	2.64[bcd]	3.59[acd]	3.92[abd]	4.49[abc]	3.80
Enhanced food quality*	2.62[bcd]	3.31[acd]	3.74[abd]	4.39[abc]	3.62
I believe that farmers will be able to produce economically profitable in the future without digital technologies such as robots.(-)	4.20[bcd]	3.47[acd]	3.27[abd]	2.88[abc]	3.35
As robots are expensive, food prices could eventually also rise.(-)	4.53[bcd]	3.77[acd]	3.31[abd]	2.93[abc]	3.50
Environment (McDonalds ω: 0.91; Cronbach's α: 0.90; λ-2: 0.91)	2.56[bcd]	3.40[acd]	3.89[abd]	4.39[abc]	3.70
Climate friendly food production*	2.64[bcd]	3.38[acd]	3.90[abd]	4.37[abc]	3.70
Enhanced biodiversity*	2.38[bcd]	3.17[acd]	3.67[abd]	4.25[abc]	3.49
Preservation of good and fertile 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
Enhanced environmental protection*	2.51[bcd]	3.51[acd]	3.93[abd]	4.52[abc]	3.76
Attract. retain. people (McDonalds ω: 0.63; Cronbach's α: 0.59; λ-2: 0.59)	2.59[bcd]	3.20[acd]	3.62[abd]	4.31[abc]	3.52
Reducing the workload on farms*	3.46[bcd]	3.98[acd]	4.49[abd]	4.81[abc]	4.29
More leisure time for farmers*	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
I believe that farmers could lose their jobs in agriculture due to the widespread use of robots.(-)	4.33[bcd]	3.52[acd]	2.91[abd]	1.93[abc]	3.06
Lifestyle and business (McDonalds ω: 0.67; Cronbach's α: 0.67; λ-2: 0.67)	4.30[bcd]	3.32[acd]	2.64[abd]	2.09[abc]	2.91
I rate the risk of society becoming more alienated from food production through the use of agricultural robots as **low**.(-)	1.82[bcd]	2.75[acd]	3.36[abd]	3.83[abc]	3.11
I believe that all types of agricultural farms could profit from robots in agriculture.	1.90[bcd]	3.00[acd]	3.67[abd]	4.16[abc]	3.38
Robot technology increases the risk that the family-run farm in Germany will become extinct.(-)	4.62[bcd]	3.71[acd]	2.94[abd]	2.27[abc]	3.22
Technology per. infrastr. (McDonalds ω: 0.61; Cronbach's α: 0.60; λ-2: 0.60)	3.95[bcd]	3.00[acd]	2.47[abd]	1.89[abc]	2.68
I rate the risk of agricultural robots being potential targets for hacker attacks and cybercrime as **low**.	1.98[bcd]	2.55[acd]	2.99[abd]	3.54[abc]	2.86
Data collection by agricultural robots gives me **little** cause for concern.	2.10[bcd]	3.00[acd]	3.49[abd]	4.16[abc]	3.32
I believe that it is difficult to integrate robots into existing production systems in agriculture.(-)	3.87[bcd]	2.83[acd]	2.36[abd]	1.88[abc]	2.57
We should intensify research on agricultural robots and invest in this field.	2.00[bcd]	3.27[acd]	3.99[abd]	4.61[abc]	3.68

Values represent mean values; Factor score means are measured after re-coding of negative polarized items; *Based on the question: *How do you estimate the influence of the use of robots in agriculture on the following areas?*; λ-2 = Guttmann's Lambda-2; [a]= statistically significant difference between the respective cluster and cluster a on the basis of p = 0.05 and respectively for [bcd] (inference based on a statistically 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 = Strongly disagree, 2 = Rather disagree, 3 = Partly/Partly, 4 = Rather agree, 5= Strongly agree; (-)= Item with negative polarization (inverted Likert type scale). Test statistics and effect sizes are provided in Appendix Table A3.
Source: own calculation

The formed clusters are characterized as follows:

Cluster A is called the *Skeptics*. At 10.8% sample share, this group forms the smallest cluster. The *Skeptics* are either unsure whether RAS should be used in crop farming (39%) or tend to reject RAS use (48%) (Figure 2).
Regarding the potential impact of RAS, the *Skeptics* perceive risks for family farms and expect jobs in agriculture to potentially be displaced. 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 (Figure 3) shows that maintaining a certain human involvement in food production is weighted statistically significant higher by the *Skeptics* compared to participants of the other clusters. Furthermore, the family farm as a guiding principle holds great importance to these people. In contrast, environmentally friendly and sustainable farming are less important. Affordable food also ranks number seven, lower than in the other three clusters. 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 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* attach importance to the family farm, albeit less than the *Skeptics*. Environmentally friendly agriculture ranks topic-wise high in third place. However, 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 statistically significant more female participants compared to the clusters with higher acceptance rates. Like the *Skeptics*, the *Skeptical Proponents* trust domestic farmers statistically significant less compared to the *Proponents* and *Enthusiasts*. In addition, the proportion of city dwellers (69.5%) is higher than for the *Skeptics* but statistically 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 a major concern of the *Proponents*. Furthermore, 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 statistically significant higher share of men, urban dwellers, and trust compared to the more skeptical clusters was already mentioned. Additionally, the *Proponents* mark, on average, the highest net household income, which is statistically significant higher compared to the skeptical clusters.

The respondents in 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 no concerns. Unlike the other three clusters, the *Enthusiasts* doubt that future farming systems will be economically viable without 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 characterized by the highest share of men (58%), city dwellers (83%), and the highest trust in farmers.

No statistical relationship was found between the cluster's average age, education, and relationship to farming. Furthermore, *Proponents* and *Enthusiasts* do not differ statistically significant regarding sociodemographic characteristics.

Table 3. Cluster describing sociodemographic variables, trust in farmers

	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
Close relationship to farming in %	9.84	10.40	10.20	8.49	9.73
Relationship to farming in %	47.56	52.40	51.28	54.71	51.49
No relationship to farming in %	42.60	37.20	38.52	36.80	38.78

Values that are not labeled differently represent mean values; [a]= difference between the respective cluster and cluster a on the basis of p = 0.05 and respectively for [bcd] (inference based on a statistically 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). Close relationship to farming = contact via work or contact via acquaintances and hobbies; relationship to farming = contact via farm holidays or contact using farm shops; no relationship to farming = no contact. Test statistics and effect sizes are provided in Appendix Table A3.
Source: own calculation

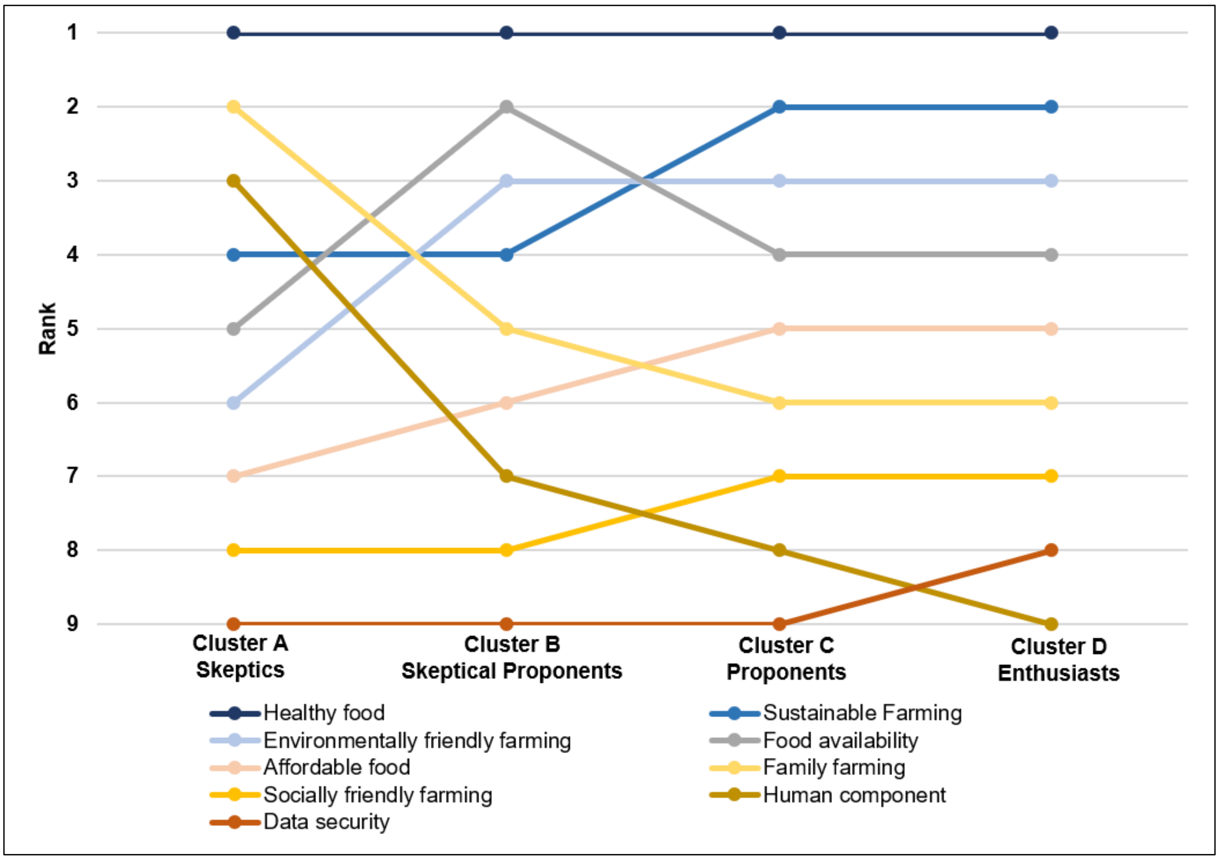

Figure 3. Agricultural topic importance ranking per cluster

(participants ranked the topic according to their personal importance from 1-most important to 9-least important. The cluster rankings were created according to the average rank. Inference statistics across the groups and exact average scores are presented in Appendix Table A1 and A3).
Source: own calculation and illustration

4.3 Political Preferences

Figure 4 illustrates the participants' party preferences according to the cluster affiliation, the overall sample preferences, and the opinion poll result of a polling provider in Germany at the time of the study. The sample closely reflects the general sentiment in Germany at the time of the survey, with only a slight underrepresentation of the Christian Democratic Party (CDU) and a minor overrepresentation of the Right-Wing Party (AfD).

Noticeably, the environmental party (Green party) generates the highest approval in the clusters of *Supporters* and *Enthusiasts* who are favorable toward RAS. In addition, the voters of the Social Democratic Party (SPD) are represented to a greater extent in the more positive clusters (C and D). No clear patterns can be identified for the Christian Democratic (CDU) parties or the Liberals (FDP). For the Right-wing Party (AfD), approval tends to lie in the more skeptical clusters (*Skeptical Proponents and Skeptics*). A similar, skeptical approval pattern compared to the right-wing party exists among non-voters. A chi-square test between the clusters and the categories with the highest variation (SPD, Green party, AfD, Non-Voters) confirms a link between cluster affiliation and political orientation (Appendix Table A1).

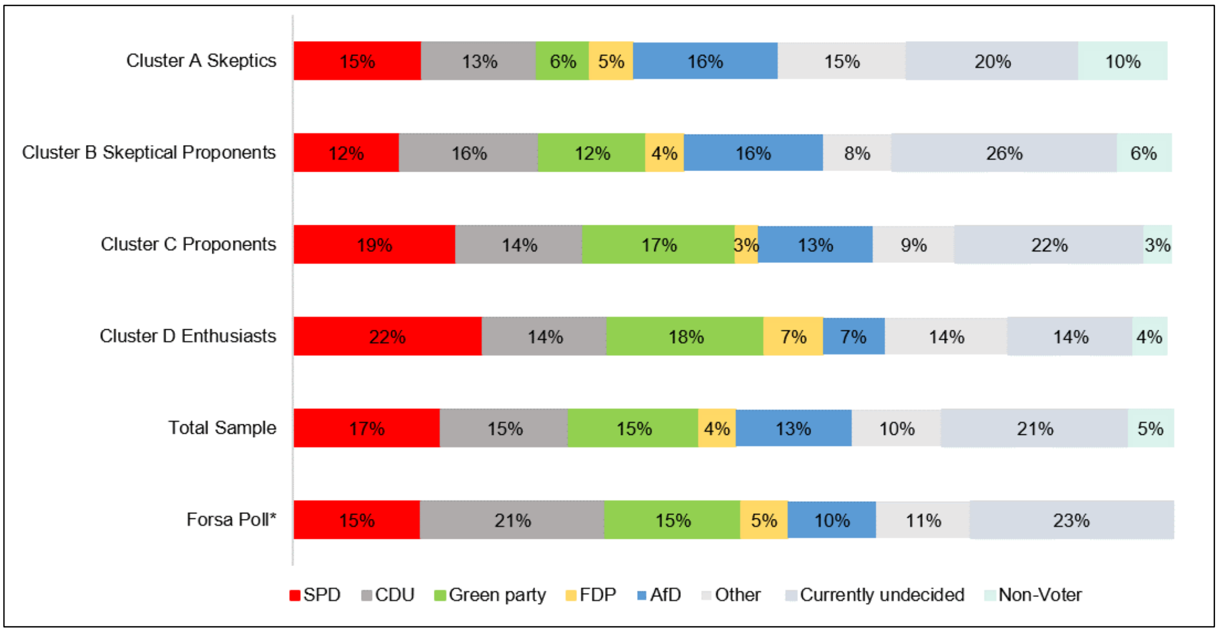

Figure 4. Share of party preferences per cluster

*Forsa Poll from 24th January 2023 according to https://www.wahlrecht.de/umfragen/forsa.htm
(the Forsa Poll does not differentiate between Non-Voters and Undecided Voters)
Source: own calculation and illustration

5 Discussion

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

5.1 RAS Potential to Ease Farm Work is Recognized, but Necessity Remains Uncertain

Regardless of the cluster affiliation, we found consensus that the technologies ease farm work. Hence, overlap exists concerning farmers' adoption perspectives as Rübcke von Veltheim et al. (2022) detected the potential ease of farm work as one of the major performance factors for the successful adoption of RAS.

Furthermore, despite high acceptance levels, participants across clusters can imagine that farmers would be able to farm successfully without RAS in the future. The social consensus is mirroring farmers' skepticism regarding RAS's economic viability (Redhead et al., 2015). Upscaling of RAS is currently rather low, as technologies are not mature and economic viability is limited to special use cases (Gil et al., 2023).

5.2 Perceived Economic and Environmental Benefits Reveal Gaps Between Segments

More diverse opinions emerged for the other areas examined in this study and confirm the chosen study approach to extend the investigation beyond the attitudinal acceptance evaluation. The skeptical clusters provide essential insights, especially since, in the past, critical voices often carried considerable weight in evaluating public acceptance of agricultural systems (Archer et al., 2008).

Skeptical participants do not recognize a positive economic contribution of the technologies in terms of improved food supply and food quality. A statistically significant gap compared to the proponents of the technology occurs, who perceive considerable potential. One initial suggestion could be a higher trust in humans 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 more skeptical participants. Rather, the findings are in line with other studies determining trust in farmers as an acceptance factor for autonomous farming (Langer, Kühl, 2023; Pfeiffer et al., 2021).

Sustainable farming practices could strengthen society's trust in agriculture. Therefore, environmental advantages serve as a compelling rationale for recommending the adoption of RAS (Sparrow, Howard, 2021). Farmers share this perspective (Rübcke von Veltheim et al., 2022) - although they 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). Furthermore, 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 acceptance of RAS in society. The potential is reflected in the response behavior of *Proponents* and *Enthusiasts*, as well as in previous studies (Zeddies et al., 2024; Wilmes et al., 2022; Pfeiffer et al., 2021).

However, not all clusters exhibit a positive attitude towards the environmental benefits of RAS. In particular, the two more skeptical clusters, which consists of more people from rural areas, are less convinced of the environmental potential of RAS. This might be related to a certain realism, as the rural population more frequently witnesses agricultural practices in their everyday lives - an important distinction to the proximity to agriculture surveyed in this study revealing no differences between the clusters. Although RAS offers sustainability potential (Ditzler, Driessen, 2022), automation alone will not achieve sustainable farming. Other technologies like genetic engineering (Qaim, 2020) and behavioral changes in land use and food consumption are likewise required (Parlasca, Qaim, 2022; Arneth et al., 2017).

5.3 Concerns About Potential Job Displacement and Structural Changes are Associated with RAS

In addition to voicing doubts about the environmental impact of RAS, more skeptical participants prioritize other topics above the environmental issues. Retaining a certain human component is prioritized, and job losses due to RAS are considered a significant risk. Concerns about job losses extend even to the *Proponents* of RAS, who are unsure how to evaluate the employment impacts. Conversely, only the *Enthusiasts* recognize the potential for new employment opportunities through RAS, which is also discussed in other sectors (Damelang, Otto, 2023).

Considering societal concerns, it is vital to communicate the necessity of using technology in agriculture due to accelerating structural change. Attracting and retaining skilled workers has become increasingly challenging for farmers, with structural changes in agriculture often leading to labor shortages (Redhead et al., 2015). RAS can address those issues. Emphasizing this narrative can enhance public acceptance of RAS (Zeddies et al., 2024). However, further research is needed to assess whether automation in agriculture poses a risk to jobs and to understand the potential consequences for rural areas and on-farm employment.

Similar to the concerns of potential job losses for agricultural workers, RAS use is critically viewed concerning potential displacements of family farms, while concurrently, the family farm is of high importance for a large share of participants. 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 and making them manageable for citizens, 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.

The related societal perspectives on shifting farm operations might influence the perception of RAS impacting farm structures. 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 himself (Blok, Long, 2016). This automation might drive the societal aspiration for human-centered family farms where it is assumed that the farmer is not anonymous (van Vliet et al., 2015).

Interestingly, the value of a family-run farm and the retention of a human component shrink with a higher level of acceptance. The high value placed on the human component could reflect a general skepticism towards technology, which is well documented for technology innovation (Khasawneh, 2018). This general skepticism could also drive concerns regarding data and cyber security issues potentially arising from automated farm machinery. Studies suggest that data regulation should be adjusted (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 raises concerns. Furthermore, information gathered by RAS could surpass the intended scope of RAS usage and raise privacy concerns. These privacy concerns have been identified as strong predictors of consumers' intentions to use drone delivery services (Yoo et al., 2018). Even if the topic is less important to the study participants than other topics, results reveal a legitimate social interest in data regulation. Therefore, data security for agricultural robots requires protection not only for users but also for those who interact indirectly with the technology.

5.4 Urban Dwellers and Male Participants Perceive Higher Potential for RAS

Looking at sociodemographic differences between the clusters, only the proportion of urban dwellers, as already discussed, and the proportion of women provide statistically significant differences among clusters. Women appear to be more critical toward RAS than men. 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).

5.5 More Right-Wing Party Voters and Non-Voters are Skeptical Towards RAS

The political landscape not only shapes the environment for successful technology adoption but is also related to individual technology acceptance of individuals, as political parties reflect and condense societal opinions. A link between political preferences and issues related to agricultural production has recently been shown for pesticide-reducing technologies and renewable energy (Saleh et al. 2024; Clulow et al. 2021).

In linking the acceptance of RAS to voting decisions or party preference, it is important to note that party preference in a cross-sectional data set such as the one presented here is a snapshot and subject to external influences. A more robust conclusion would require a panel data analysis.

Nevertheless, the results show notable links between perceptions of RAS and political attitudes. In Germany, each major political party has outlined an agricultural policy strategy for the 2021 national elections. These strategies included objectives related to the use of digital technologies in agriculture. By comparing these party-specific goals with their voters' attitudes toward RAS, patterns of alignment or divergence patterns can be identified. Additionally, given the frequent mention of Genome Editing and genetically modified organisms in these strategies, these technologies are also included in the party-specific analysis.

All parties besides the Social Democrats (SPD) and the right-wing conservative party (AfD) mention digital solutions as a crucial driver for modern and sustainable farming systems, while none of the parties mention autonomous systems particularly (AfD, 2021; Bündnis90/Die Grünen, 2021; CDU, 2021; FDP, 2021; SPD, 2021). The Liberals (FDP) and Christ Democrats (CDU) favor the approval of Genome Editing.

The Green (environmental) party and SPD mention technological solutions as a contributor to sustainability regardless of the specific economic sector (Bündnis90/Die Grünen, 2021; SPD, 2021). This sustainability advantage is also recognized for RAS by the voters as an above-average number of the Green party and SPD voters can be found among the more positive clusters. As a party concerned with social equality (Debus, 2009), the risk of job losses for agricultural workers does not seem to play a major role for SPD voters. On the other hand, the perceived benefits, especially sustainability potentials, could outweigh this argument. Interestingly, the Greens and the SPD, in particular, hesitate to vote for socially critical technologies such as Genome Editing (Bündnis90/Die Grünen, 2021; SPD, 2021). This restraint is not to be anticipated for RAS, given the party programs and voter preferences. Future research should, therefore, focus on whether parts of society perceive RAS as a substitute for less accepted technologies such as genetic engineering or whether the sustainability potential of different technologies is recognized as a bundle of measures to achieve the goal of sustainable food production.

The cluster affiliation tendency of the right-wing voters (AfD) towards the more skeptical cluster mirrors the goals of preserving rural smallholder farmers and a German-centered agricultural policy (AfD, 2021). Concerns that the use of RAS will reduce the proportion of family farms and change the structure of rural employment are more pronounced in these clusters. Many AfD voters reside in rural areas, building a statistically significant higher proportion of *Skeptical Proponents and Skeptics* in this study (Heinisch, Werner, 2019). The party's agricultural policy orientation thus reflects some of the concerns already expressed towards RAS use. Nevertheless, a certain inconsistency arises as the AfD advocates using precision farming technologies in their latest agricultural policy strategy (AfD, 2023). Skepticism can further be observed among non-voters, which aligns with the findings of a study among German voters, finding general skepticism and dissatisfaction among non-voters regarding political issues (Koch et al., 2023). This highlights the need for alternative communication channels, such as active farmer engagement with skeptical people, leveraging the high visibility of RAS in the fields. However, this approach requires an interest in learning about modern farming systems.

5.6 Limitations

The choice and presentation of the RAS, as well as the explanation, influenced the study results. Therefore, the explanations were kept as neutral as possible and adapted in numerous iterative processes during the study design.

There is no established framework for measuring public acceptance of RAS. This study represents a first attempt to systematize public acceptance by integrating relevant dimensions identified in previous research (Pfeiffer et al., 2021; Sparrow, Howard, 2021; Spykman et al., 2022; Wilmes et al., 2022; Mohr, Höhler, 2023). However, given the exploratory nature of this research, alternative questions or item statements could lead to different results. Future studies could extend this work by using confirmatory approaches to validate the proposed classification.

Contextual and cultural factors may also influence the results. To address this, we included political preference as a factor, also suggested by Langer et al. (2024). However, this is just one of many factors - such as norms, values, media coverage, and legal regulations - that future studies could explore to assess their impact on acceptance further. Geographically, this study is limited to Germany. While the implications may be valid for other developed countries with similar population structures, there is a great need for research into how RAS could influence agricultural systems in less developed countries.

Outside the scope of this study was the actual evaluation of the presented technologies in the field by laypersons. Future studies could fill this research gap with qualitative methods.

6 Conclusion

The idea of RAS has been with farmers for decades. Recent advances in artificial intelligence bring this vision closer to becoming a reality. Understanding the drivers and barriers to RAS acceptance is paramount, not only for society but also for recognizing the diverse perspectives across societal segments.

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 and identified four clusters with varying acceptance levels regarding RAS.

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 economic and 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.

This study highlights that focusing communication on the sustainability potential of RAS, often emphasized in outreach to non-farming communities (Mohr, Höhler, 2023), may not suffice for widespread acceptance, as broader societal concerns related to farming systems are tied to RAS use. It is important to communicate that these technologies have potential for all types of farms and do not inherently drive structural change.

The analyzed political parties in Germany support the use of precision agriculture. Consequently, political backing for adopting RAS is anticipated, which is important for widespread RAS acceptance as political parties reflect and condense societal opinions. Associations between the different segments and the political preferences have been identified. Environmental and social democratic party voters highly recognize RAS benefits. However, the analysis highlights that skepticism toward RAS is associated with preferences for the right-wing conservative party. While this skepticism does not align with the party's general policy direction regarding RAS, it reflects broader conservative agricultural objectives, such as market protection policies. These policies aim to counteract structural change, which, in turn, drives societal skepticism toward RAS. This underscores the importance of addressing broader socioeconomic implications in discussions about automated agriculture rather than solely emphasizing sustainability benefits.

Author Contributions

Both authors contributed to the development of the ideas and the study design. Hendrik Hilmar Zeddies implemented the survey, managed data collection, and prepared the results. Both authors supported the interpretation of the results. Hendrik Hilmar Zeddies wrote the paper with input from Gesa Busch.

Code and Data Availability

Code and data underlying this article are available at the PhenoRob database “Phenoroam”: https://phenoroam.phenorob.de/geonetwork/srv/eng/catalog.search#/metadata/4c490b24-3c86-40e4-a59c-b44098cffe7f/.

Funding

This work was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany’s Excellence Strategy—EXC 2070-390732324-PhenoRob.

Competing Interests

The authors declare no competing interests.

Additional Information

Correspondence and requests for materials should be addressed to Hendrik Hilmar Zeddies.

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Appendix

Additional Statistical Analysis

Table A1. 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
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^{cd}/4	4.60^{cd}/4	3.98^{ab}/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
Test of independence: Political preferences	Comparing the party preference for the parties SPD, Green Party, AfD, and Non-Voters between the clusters, the following chi-squared test-statistic was derived: χ^2= 18.73, df = 9, p-value = 0.02759.				

Values represent mean values; ^{a}= Statistically significant difference between the respective cluster and cluster a on the basis of p=0.05 and respectively for ^{bcd} (inference based on a statistically significant Kruskal-Wallis test and group-wise comparisons with the Dunn post-hoc test).
Source: own calculation

Table A2. Average cluster responses – Robustness check using K-means method

Item	**Cluster A Skeptics** n = 36 (6.3%)	**Cluster B Skeptical Proponents** n = 158 (27.9%)	**Cluster C Proponents** n = 261 (46.0%)	**Cluster D Enthusiasts** n = 112 (19.8%)	**Total Sample** n = 567
Community acceptance (McDonalds ω: 0.89; Cronbach's α: 0.89; λ-2: 0.89)	2.10[bcd]	3.49[acd]	4.22[abd]	4.86[abc]	4.01
Economics and viability (McDonalds ω: 0.65; Cronbach's α: 0.60; λ-2: 0.60)	1.94[bcd]	2.81[acd]	3.27[abd]	3.68[abc]	3.14
Environment (McDonalds ω: 0.91; Cronbach's α: 0.90; λ-2: 0.91)	2.15[bcd]	3.30[acd]	3.86[abd]	4.38[abc]	3.70
Attract. & retain. people (McDonalds ω: 0.63; Cronbach's α: 0.59; λ-2: 0.59)	2.35[bcd]	3.13[acd]	3.61[abd]	4.21[abc]	3.52
Lifestyle and business (McDonalds ω: 0.67; Cronbach's α: 0.67; λ-2: 0.67)	4.46[bcd]	3.53[acd]	2.72[abd]	2.00[abc]	2.91
Technology per. & infrastr. (McDonalds ω: 0.61; Cronbach's α: 0.60; λ-2: 0.60)	4.10[bcd]	3.14[acd]	2.55[abd]	1.87[abc]	2.68
Group characteristics					
Average age	53.66	47.86	47.62	50.26	48.59
Share of women in %	58.33%[cd]	60.76%[cd]	46.73%[b]	41.96%[b]	49.56%
Average education[1]	2.75	2.94	3.09	3.08	3.03
Average income[2]	2.28[c]	2.32[c]	2.66[ab]	2.68	2.55
Share of city dwellers in %	52.78%[cd]	71.52%	77.01%[a]	82.14%[a]	74.96%
Trust in farmers	2.92[cd]	3.16[d]	3.29[a]	3.47[ab]	3.27
Close relationship to farming in %	13.90	10.80	9.58	8.04	9.73
Relationship to farming in %	41.63	50.00	53.20	54.50	51.49
No relationship to farming in %	44.47	39.20	37.22	37.46	38.78

Values represent mean values; factor score means are measured after re-coding of negative polarized items; *Based on the question: h*ow do you estimate the influence of the use of robots in agriculture on the following areas?*; λ-2 = Guttmann's Lambda-2; [a]= statistically significant difference between the respective cluster and cluster a on the basis of p = 0.05 and respectively for [bcd] (inference based on a statistically 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 = Strongly disagree, 2 = Rather disagree, 3 = Partly/Partly, 4 = Rather agree, 5 = Strongly agree; (-) = Item with negative polarization (inverted Likert type scale); 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). Close relationship to farming = Contact via work or contact via acquaintances and hobbies; relationship to farming = contact via farm holidays or contact using farm shops; no relationship to farming = no contact.
Source: own calculation

Table A3. Test statistics Kruskal-Wallis test and Dunn test post-hoc analysis

Item	A vs. B		A vs. C		A vs. D		B vs. C		B vs. D		C vs. D	
	μ(z)	**r**	**μ(z)**	**r**	**μ(z)**	**r**	**μ(z)**	**r**	**μ(z)**	**r**	**μ(z)**	**r**
Community acceptance	2.56/3.59***(-4.39)	.29	2.56/4.29***(-11.81)	.69	2.56/4.84***(-16.14)	1.25	3.59/4.29***(-10.21)	.51	3.59/4.84***(-15.54)	.96	4.29/4.84***(-7.68)	.42
Should robots like the ones you have seen before be used in agriculture?	2.46/3.47***(-4.64)	.31	2.46/4.23***(-11.11)	.64	2.46/4.79***(-14.51)	1.12	3.47/4.23***(-8.86)	.44	3.47/4.79***(-13.13)	.80	4.23/4.79***(-6.30)	.34
I believe that the use of robot machines is the future of agriculture.	2.49/3.60***(-4.92)	.33	2.49/4.22***(-10.18)	.59	2.49/4.78***(-14.20)	1.10	3.60/4.22***(-7.13)	.36	3.60/4.78***(-12.40)	.76	4.22/4.78***(-7.01)	.38
Robots could be of great benefit to agriculture.	2.74/3.69***(-5.19)	.35	2.74/4.31***(-10.66)	.62	2.74/4.87***(-14.59)	1.13	3.69/4.31***(-7.40)	.37	3.69/4.87***(-12.57)	.77	4.31/4.87***(-6.96)	.38
I would buy food produced with the help of robots.	2.54/3.62***(-4.71)	.31	2.54/4.40***(-10.89)	.63	2.54/4.93***(-14.17)	1.10	3.62/4.40***(-8.44)	.42	3.62/4.93***(-12.60)	.77	4.40/4.93***(-6.09)	.33
Economics and viability	2.14/2.92***(-4.39)	.29	2.14/3.27***(-11.81)	.69	2.14/3.77***(-16.14)	1.25	2.92/3.27***(-10.21)	.51	2.92/3.77***(-15.54)	.95	3.27/3.77***(-7.68)	.42
Secured food supply	2.64/3.59***(-6.70)	.45	2.64/3.92***(-10.12)	.59	2.64/4.49***(-13.61)	1.05	3.59/3.92***(-4.41)	.22	3.59/4.49***(-9.48)	.58	3.92/4.49***(-6.27)	.34
Enhanced food quality	2.62/3.31***(-4.26)	.28	2.62/3.74***(-8.36)	.49	2.62/4.39***(-12.30)	.95	3.31/3.74***(-5.53)	.28	3.31/4.39***(-10.73)	.65	3.74/4.39***(-6.63)	.36
I believe that farmers will be able to produce economically profitable in the future without digital technologies such as robots.(-)	4.20/3.47***(4.74)	.32	4.20/3.27***(6.70)	.39	4.20/2.88***(8.30)	.64	3.47/3.27*(2.46)	.12	3.47/2.88***(4.99)	.30	3.27/2.88**(3.18)	.17
As robots are expensive, food prices could eventually also rise.(-)	4.53/3.77***(5.09)	.34	4.53/3.31***(8.70)	.50	4.53/2.93***(9.96)	.77	3.77/3.31***(4.79)	.24	3.77/2.93***(6.72)	.41	3.31/2.93**(3.00)	.16
Environment	2.56/3.40***(-4.91)	.33	2.56/3.89***(-10.82)	.63	2.56/4.39***(-13.87)	1.07	3.40/3.89***(-8.04)	.40	3.40/4.39***(-11.97)	.73	3.89/4.39***(-5.77)	.31
Climate friendly food production*	2.64/3.38***(-4.73)	.32	2.64/3.90***(-9.25)	.54	2.64/4.37***(-11.89)	.92	3.38/3.90***(-6.10)	.31	3.38/4.37***(-9.64)	.59	3.90/4.37***(-4.97)	.27
Enhanced biodiversity*	2.38/3.17***(-4.39)	.29	2.38/3.67***(-8.72)	.51	2.38/4.25***(-11.69)	.90	3.17/3.67***(-5.85)	.29	3.17/4.25***(-9.80)	.60	3.67/4.25***(-5.36)	.29
Preservation of good and fertile soils*	2.61/3.51***(-5.46)	.36	2.61/3.98***(-10.16)	.59	2.61/4.41***(-12.45)	.96	3.51/3.98***(-6.31)	.32	3.51/4.41***(-9.49)	.58	3.98/4.41***(-4.64)	.25
Ecosystem protection*	2.66/3.44***(-4.48)	.30	2.66/3.98***(-9.43)	.55	2.66/4.43***(-12.19)	.94	3.44/3.98***(-6.72)	.34	3.44/4.43***(-10.32)	.63	3.98/4.43***(-5.16)	.28
Enhanced environmental protection*	2.51/3.51***(-5.70)	.38	2.51/3.93***(-9.56)	.55	2.51/4.52***(-13.25)	1.03	3.51/3.93***(-5.10)	.26	3.51/4.52***(-10.23)	.62	3.93/4.52***(-6.46)	.35
Attract. & retain. People	2.59/3.20***(-4.32)	.29	2.59/3.62***(-9.82)	.57	2.59/4.31***(-15.20)	1.18	3.20/3.51***(-7.50)	.38	3.20/4.31***(-14.40)	.88	3.51/4.31***(-8.82)	.48
Reducing the workload on farms*	3.46/3.98*(-2.55)	.17	3.46/4.49***(-7.71)	.45	3.46/4.81***(-10.37)	.80	3.98/4.49***(-7.13)	.36	3.98/4.81***(-10.30)	.63	4.49/4.81***(-4.78)	.26
More leisure time for farmers*	3.33/3.81*(-2.63)	.18	3.33/3.99***(-4.41)	.26	3.33/4.52***(-8.34)	.65	3.81/3.99*(-2.35)	.12	3.81/4.52***(-7.59)	.46	3.99/4.52***(-6.04)	.33
Jobs in agriculture*	1.99/2.54***(-3.77)	.25	1.99/2.91***(-6.21)	.36	1.99/3.83***(-10.16)	.79	2.54/2.91**(-3.22)	.16	2.54/3.83***(-8.57)	.52	2.91/3.83***(-6.34)	.34
I believe that farmers could lose their jobs in agriculture due to the widespread use of robots.(-)	4.33/3.52***(4.24)	.28	4.33/2.91***(8.33)	.48	4.33/1.93***(12.69)	.98	3.52/2.91***(5.51)	.28	3.52/1.93***(11.26)	.69	2.91/1.93***(7.21)	.39
Lifestyle and business	4.30/3.32***(4.97)	.33	4.30/2.64***(11.70)	.68	4.30/2.09***(14.39)	1.11	3.32/2.64***(9.20)	.46	3.32/2.09***(12.57)	.77	2.64/2.09***(5.40)	.29
I rate the risk of society becoming more alienated from food production through the use of agricultural robots as low.(-)	1.82/2.75***(-4.59)	.31	1.82/3.36***(-9.14)	.53	1.82/3.83***(-10.90)	.84	2.75/3.36**(-6.14)	.31	2.75/3.83***(-8.53)	.52	3.36/3.83***(-3.75)	.20
I believe that all types of agricultural farms could profit from robots in agriculture.	1.90/3.00***(-5.40)	.36	1.90/3.67***(-10.60)	.62	1.90/4.16***(-12.42)	.96	3.00/3.67***(-7.02)	.35	3.00/4.16***(-9.52)	.58	3.67/4.16***(-4.04)	.22

Item	A vs. B μ(z)	r	A vs. C μ(z)	r	A vs. D μ(z)	r	B vs. C μ(z)	r	B vs. D μ(z)	r	C vs. D μ(z)	r
Robot technology increases the risk that the family-run farm in Germany will become extinct.(-)	4.62/3.71***(4.97)	.33	4.62/2.94***(10.00)	.58	4.62/2.27***(12.17)	.94	3.71/2.94***(6.73)	.34	3.71/2.27***(9.71)	.59	2.94/2.27***(4.49)	.24
Technology per. & infrastr.	3.95/3.00***(5.29)	.35	3.95/2.47***(11.93)	.69	3.95/1.89***(15.55)	1.20	3.00/2.47***(9.06)	.45	3.00/1.89***(13.69)	.83	2.47/1.89***(6.72)	.36
I rate the risk of agricultural robots being potential targets for hacker attacks and cybercrime as low.	1.98/2.55**(-3.24)	.22	1.98/2.99***(-6.25)	.36	1.98/3.54***(-8.46)	.66	2.55/2.99***(-4.06)	.20	2.55/3.54***(-7.01)	.43	2.99/3.54***(-3.94)	.21
Data collection by agricultural robots gives me little cause for concern.	2.10/3.00***(-4.30)	.29	2.10/3.49***(-7.64)	.44	2.10/4.16***(-10.60)	.82	3.00/3.49***(-4.45)	.22	3.00/4.16***(-8.49)	.52	3.49/4.16***(-5.18)	.28
I believe that it is difficult to integrate robots into existing production systems in agriculture(-)	3.87/2.83***(5.54)	.37	3.87/2.36***(9.26)	.54	3.87/1.88***(11.34)	.88	2.83/2.36***(4.92)	.25	2.83/1.88***(7.96)	.48	2.36/1.88***(4.21)	.23
We should intensify research on agricultural robots and invest in this field.	2.00/3.27***(-5.83)	.39	2.00/3.99***(-11.76)	.68	2.00/4.61***(-15.05)	1.16	3.27/3.99***(-8.02)	.40	3.27/4.61***(-12.38)	.75	3.99/4.61***(-6.23)	.34
Group characteristics												
Average age												
Share of women in %	-	-	67.21/44.07**(3.22)	.19	67.21/42.44**(3.08)	.24	58.54/44.07**(2.84)	.19	58.54/42.44*(2.58)	.16	-	-
Average education												
Average income	-	-	2.33/2.70*(-2.71)	.16	2.34/2.70**(-2.71)	.28	-	-	-	-	-	-
Share of city dwellers in %	-	-	62.30/78.39*(-2.58)	.15	62.30/83.02**(-3.08)	.24	69.51/78.39**(-2.01)	.10	69.51/83.02*(-2.58)	.15	-	
Trust in farmers	-	-	2.99/3.32*(-2.85)	.17	2.99/3.50**(-3.48)	.27	3.14/3.32*(-2.64)	.13	3.14/3.50**(-3.35)	.21	-	
Close relationship to farming in %												
Relationship to farming in %												
No relationship to farming in %												
Topic preferences												
Healthy food												
Sustainable farming (for future generations)	-	-	4.84/3.98*(2.33)	.14	4.84/3.73*(2.89)	.22	4.60/3.98*(2.52)	.13	4.60/3.73*(3.10)	.19	-	-
Environmentally friendly farming	-	-	5.23/4.10**(-3.04)	.18	5.23/3.81**(-3.53)	.27	-	-	-	-	-	-
Food availability												
Affordable food												
Family farming	-	-	4.30/5.32*(-2.94)	.23	-	-	-	-	-	-	-	-
Socially friendly farming												
Human component	4.41/5.74**(-3.17)	.21	4.41/6.60***(-5.75)	.33	4.41/7.17***(-6.85)	.53	5.74/6.60**(-3.43)	.17	5.74/7.17***(-5.01)	.30	6.60/7.17*(-2.36)	.13
Data security												

A = Skeptics, B = Skeptical Proponents, C = Proponents, D = Enthusiasts, μ = mean values of the variables for the respective group z = z-statistic group-wise comparison r = Wilcoxon Effect Size ($Z/\sqrt{N}$) *, **, and ***indicate statistically significant differences in mean at the 5%, 1%, and .1% levels; - = statistically insignificant Dunn test at a 5% level; hatched = statistically insignificant Kruskal-Wallis test on a 5% level; categories according to Table 2, 3 and Appendix Table A1

Source: own calculation

Translated description of RAS technologies and *original German description*

(For image rights reasons, the corresponding images are only shown in the review process and cannot be published. Please refer to Zeddies et al. (2024) to retrieve the images.)

Picture 1 shows a drone fertilizing a field.
German: Bild 1 zeigt eine Drohne, die ein Feld düngt.

For comparison, see how this is done conventionally, with a fertilizer spreader attached to a tractor (Picture 2).
German: Zum Vergleich sehen Sie, wie dies bisher gemacht wird, mit einem Düngerstreuer, der an einen Traktor angehängt ist (Bild 2).

Picture 3 shows a robot that uses a camera to detect weeds. The robot then sprays only the identified weeds with herbicides for weed control.
German: Bild 3 zeigt einen Roboter, der mithilfe einer Kamera Unkräuter erkennt. Der Roboter besprüht dann nur die identifizierten Unkräuter mit Herbiziden zur Unkrautbekämpfung.

The usual technique for this is the crop protection sprayer pulled by a tractor (Picture 4). Here, the entire area is sprayed with herbicides.
German: Die übliche Technik hierfür ist die Pflanzenschutzspritze, die von einem Trecker gezogen wird, wobei hier die gesamte Fläche mit Herbiziden behandelt wird (Bild 4).

Picture 5 shows a tractor-operated robot driving autonomously.
German: Bild 5 zeigt einen allein fahrenden Traktorroboter bei der Bodenbearbeitung.

The usual counterpart is larger and requires a driver (Picture 6).
German: Das übliche Gegenstück ist größer und benötigt einen Fahrer (Bild 6).

All robot examples are characterized by the fact that the systems can perform tasks independently in the field based on a defined algorithm without human control after respective programming by the farmer.
German: Alle Roboterbeispiele zeichnen sich dadurch aus, dass die Systeme die Aufgaben anhand eines definierten Algorithmus eigenständig, ohne menschliche Steuerung, auf dem Feld ausführen können.

Additional Figures

Figure A1. Original categories developed by Eastwood et al. (2019)

*Categories adapted for this study. Animal welfare does not apply to the case of RAS use in crop farming

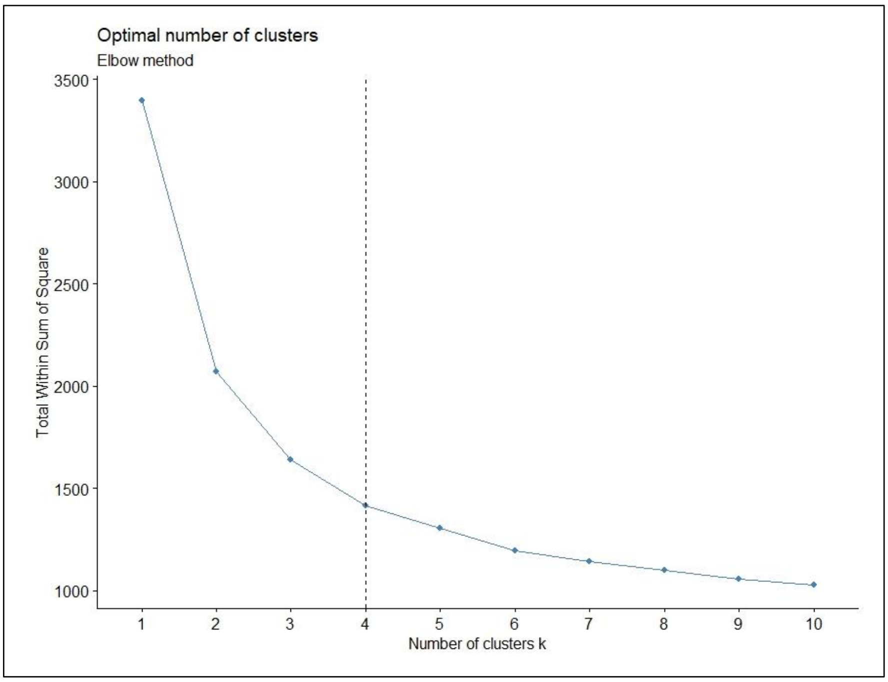

Figure A2. Optimal cluster solution suggested by R employing the Elbow Criterium

Source: own calculation and illustration