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# Cattle grazing under trees: German farmers' intentions to adopt modern silvopastoral systems under climate change risk perceptions

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**Abstract**

CONTEXT: Modern silvopastoral systems offer benefits that are important for farm climate change adaptation, including shade for grazing animals, microclimate regulation, and contributions to biodiversity conservation. In 2023, Germany revised its regulatory framework to facilitate the adoption of agroforestry systems. Despite the benefits, farmers hesitate to adopt these systems.

OBJECTIVE: Understanding farmer perceptions of silvopastoral systems and adoption barriers is essential for policy makers who aim to foster their adoption. This study investigates behavioral factors that influence cattle farmers' intentions to adopt modern silvopastoral systems for cattle grazing in combination with timber production.

METHODS: We develop a model based on a dual appraisal approach and hypothesize that farmers' technical and social appraisals of the silvopastoral system as well as their appraisals of their current pasture systems and perceptions of climate change risk predict the intention to adopt these systems. Using survey data of 174 cattle farms that hold cattle on pasture in Germany, we test our hypotheses using Partial Least Squares Structural Equation Modelling (PLS-SEM).

RESULTS AND CONCLUSIONS: We find that farmers perceive benefits from silvopastoral systems, in particular for animal wellbeing on pasture and biodiversity conservation. Along with the identification with the system, perceptions of the benefits for biodiversity and farm profitability, economic concerns, as well as the farms' perceived capability of adoption show the strongest associations with adoption intentions. The farmers' perceptions of the climate change risk of their current system influences their intentions to adopt indirectly through their attitude towards keeping the current system and perceived benefits of silvopasture. The results suggest that to increase adoption of silvopastoral systems, economic concerns should be targeted and opportunities supported.

**JEL Codes**: Q15, Q18, Q54, Q57

**Keywords**: Agroforestry, Farmer behavior, Climate change adaptation, Socio-psychological model

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# 1 Introduction

Grasslands are important for habitat provision and biodiversity in agricultural landscapes (Petermann and Buzhdygan, 2021). They also deliver crucial ecosystem services, such as water and climate regulation and carbon sequestration (Nippert *et al.*, 2022; Sirimarco *et al.*, 2018). These services depend on management practices, mowing and grazing intensity, and climatic factors such as droughts (Schils *et al.*, 2022; Abdalla *et al.*, 2018). However, climate change, grassland intensification or abandonment, and land use change increasingly put grasslands under pressure, reducing productivity and ecosystem functionality (Pazúr *et al.*, 2024; Schils *et al.*, 2022; Dellar *et al.*, 2018).

Silvopastoral agroforestry systems, which integrate trees and pastureland on the same land unit, have been proposed to enhance resilience against climate extremes (Mele *et al.*, 2019; Schoeneberger *et al.*, 2012; Hernández-Morcillo *et al.*, 2018). By creating habitats and heterogeneous microclimates, these systems can enhance biodiversity and climate-regulating functions (Torralba *et al.*, 2016). Grazing ruminants benefit from shade provision through the reduction of thermal discomfort (van Laer *et al.*, 2015). Additionally, integrating trees offers alternative forage and income sources, enhancing farm resilience (Mele *et al.*, 2019). Modern silvopastoral systems are adapted to accommodate mechanized farming practices and trees are used for profit. In 2023, Germany has revised its regulatory framework and introduced a new land use category for agroforestry. The objective is to facilitate the integration, harvest, and removal of trees and hedges for productive purposes, i.e. fruits, timber, biomass, on cropland or grassland. This stands in contrast to non-productive landscape elements or orchard meadows which are protected and cannot easily be removed. In addition, trees in agroforestry land use are part of the agricultural land, such that the income support from the Common Agricultural Policy (GAP) is paid based on the whole of the agroforestry plot area. Despite the advantages and policy support, the uptake of agroforestry and participation in subsidy programs remain low (BMEL, 2023, 2024).

Silvopasture can economically outperform single-use grassland systems, but often it does not (Möndel, Brix and Chalmin, 2009; Thiesmeier and Zander, 2023). Financial profitability is crucial for adoption of practices (Pröbstl-Haider *et al.*, 2016), yet farmers also consider further factors such as animal welfare improvements (Owusu-Sekyere, Hansson and Telezhenko, 2022), environmental benefits (Greiner and Gregg, 2011), as well as flexibility in land use (Schulze *et al.*, 2024). Climate change, by increasing the value of shade provision and local climate regulation, might increase farmers' perceptions of the merits of silvopastoral systems, possibly leading to increased adoption.

This study examines German cattle farmers' intentions to adopt a silvopastoral system that combines cattle grazing and timber production under perceived climate vulnerabilities. We expand and contextualize models for the adoption intention of farmers as a reasoned action (Ajzen, 1991). We use a dual appraisal approach (Rogers, 1975) based on the hypothesis that farmers' adoption intentions are driven by their perceptions of their current systems (e.g., climate risks) and of the possible silvopastoral modification to their current systems (e.g., benefits and adaptation costs). We also include social norms and identification with the silvopastoral system as key factors.

Behavioral studies on agroforestry adoption in Europe (Borremans *et al.*, 2016; Otter and Deutsch, 2023; Beer and Theuvsen, 2019; Felton *et al.*, 2023) appear to have limited external validity for the specific case of silvopastoral systems. Farmers perceive temperate silvoarable and silvopastoral systems differently, with many expressing greater openness to silvopastoral systems (Borremans *et al.*, 2016; Sereke *et al.*, 2016). Only few studies in Europe assess specific agroforestry systems or systems with cattle explicitly (Warren *et al.*, 2016; Opdenbosch and Hansson, 2023; Irwin *et al.*, 2023). However, behavioral studies on agroforestry adoption in Europe only look at the appraisal of the system to be adopted while disregarding the perceptions and appraisal of their current system. With climate change, farmers with grazing cattle might be especially motivated to adopt silvopastoral systems to enhance shade for grazing livestock and balance grassland microclimates. Investigating how perceptions of climate-related risks and threats of the current system influence the intention to adopt silvopastoral systems is crucial to addressing adoption barriers.

Using survey data from 174 German cattle farms, we apply Partial Least Squares Structural Equation Modelling (PLS-SEM) to evaluate our conceptual model. Unlike most agroforestry adoption studies, we present a specific silvopastoral system to respondents to enhance clarity, reduce understanding bias, and improve the reliability of their responses. This study also contributes to the literature by expanding behavioral adoption frameworks to include insights into appraisals of both prospective and current systems, thus providing a deeper understanding of adoption barriers and drivers.

The remainder of the paper is as follows: Section 2 proposes the conceptual framework for the analysis. Section 3 describes materials and methods. Results are presented in section 4 and discussed in section 5. Section 6 concludes.

# 2 Conceptual framework

## 2.1 Conceptual model

We analyze cattle farmers' intention to adopt a modern silvopastoral system (SP) as a predictor of actual adoption (Ajzen, 1991). Our conceptual model roots in Protection Motivation Theory (Rogers, 1975; Floyd, Prentice-Dunn and Rogers, 2000), the Theory of Planned Behavior (Ajzen, 1991; Fishbein and Ajzen, 2010), and the Unified Theory of Technology Acceptance and Use (UTAUT 2) (Venkatesh, Morris and Davis, 2003; Venkatesh, Thong and Xu, 2012) and takes a dual perspective (Gesk, Wichmann and Leyer, 2021; Mitter *et al.*, 2019). The dual perspective is based on Protection Motivation Theory, which originally separates between threat and coping appraisals to explain behavior.

Climate change adaptation efforts are linked to beliefs about climate change severity and personal vulnerability (Grothmann and Patt, 2005; Arbuckle, Morton and Hobbs, 2015). As SP are a potential adaptation measure, we examine whether farmers' perceptions of future risk influence their adoption intentions. Switching from current single land use (SLU) pastures to SP may only be valued if the perceived risk is high. Using Protection Motivation Theory's dual appraisal framework, we adapt threat appraisal to assess the SLU, and coping appraisal to assess the SP. Within the appraisal of the SLU, our model incorporates the attitude towards the current system, perceptions of climate change risk, and avoidance of adaptation (Grothmann and Patt, 2005; Mitter *et al.*, 2019). In the appraisal of the SP, we assess technical and social appraisals including self-identity as key SP adoption drivers (van Dijk *et al.*, 2016; Dessart, Barreiro-Hurlé and van Bavel, 2019) (see Figure 1).

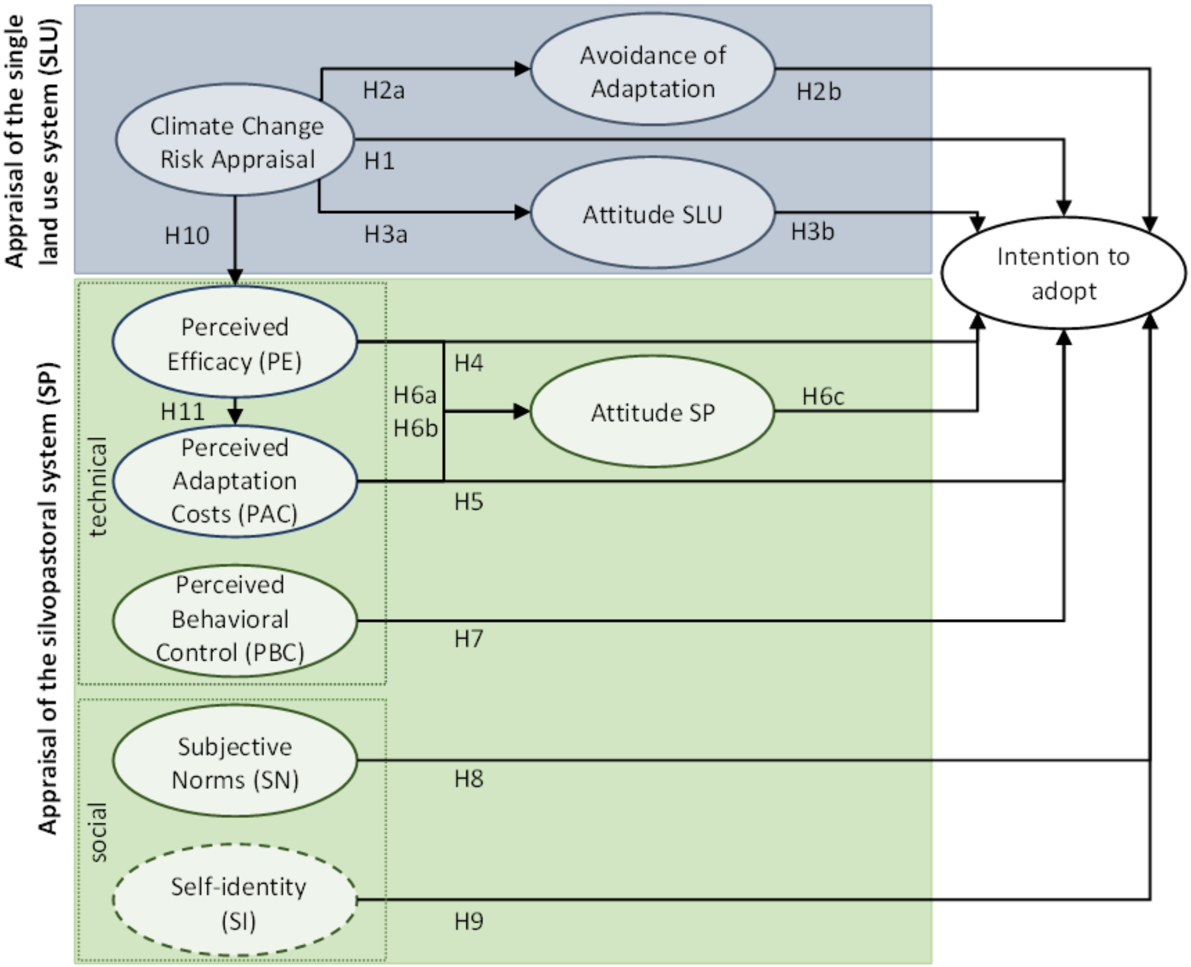


**Figure 1: Conceptual model for analyzing the intention to adopt a modern silvopastoral system**
Note: the ovals represent constructs. Self-identity is dashed as we include it for exploratory purposes and decide during model selection stage whether to include or exclude it.

## 2.2 Constructs and hypotheses

**Appraisal of the single land use system (SLU)**

The reflective construct Climate Change Risk Appraisal (CC Risk Appraisal) captures the survey respondents' (dis)agreement regarding whether certain negative consequences caused by climate change are likely to affect their farms in the next ten years (Mitter *et al.*, 2019). This leads to our first hypothesis (H1):

**H1**: CC Risk Appraisal positively affects the intention to adopt SP

In the formative construct Avoidance of Climate Change Adaptation (Avoidance) we include fatalism and denial of climate change effects (Mitter *et al.*, 2019), and whether the farmer would rather give up grazing instead. In H2 we hypothesize that the Avoidance construct moderates the CC Risk Appraisal effect:

**H2**: Avoidance is a mediator for the link of CC Risk Appraisal and the intention to adopt SP

Attitude SLU is a bipolar, reflective construct designed to directly capture a farmer's attitude towards keeping the current system (Ajzen, 1991). Following Gesk, Wichmann and Leyer (2021), in H3 we hypothesize that the Attitude SLU construct moderates CC Risk Appraisal:

**H3**: Attitude SLU is a mediator for the link between CC Risk Appraisal and the intention to adopt SP

**Appraisal of the modern silvopastoral system (SP)**

The appraisal of the modern silvopastoral system is grouped into technical and social constructs. The formative construct Perceived Efficacy (PE) captures the perceived effectiveness of the SP to achieve a set of positive effects (Floyd, Prentice-Dunn and Rogers, 2000). We hypothesize that farmers with a higher CC Risk Appraisal perceive a higher efficacy of the modern silvopastoral system (Lasco, Espaldon and Habito, 2016). This leads to two hypotheses:

**H4**: PE positively affects the intention to adopt SP

**H10**: CC Risk Appraisal is positively associated with PE

We adapt the formative construct Perceived Adaptation Costs (PAC) from Mitter *et al.* (2019) to capture concerns, fears, and insecurities linked to the adoption of SP. These include policy security, long amortization periods, loss of pasture yield through tree rows and shading, and higher management efforts. Unlike Gesk, Wichmann and Leyer (2021), we integrate fear in PAC, but like them we include a link between PE and PAC. We hypothesize that if a farmer perceives a higher efficacy of the silvopastoral system, they will perceive adaptation costs to be lower:

**H5**: PAC negatively affects the intention to adopt SP

**H11**: PE is negatively associated with PAC

Attitude SP is, similar to Attitude SLU, a reflective, bipolar construct that captures farmers' attitudes towards the modern silvopastoral system. We hypothesize in H6 that the constructs PE and PAC are mediated by the reflective construct of farmer attitude towards the modern silvopastoral system (Attitude SP) (Gesk, Wichmann and Leyer, 2021).

**H6**: Attitude SP is a mediator of the links between PE and PAC, and the intention to adopt SP

Perceived Behavioral Control (PBC) is linked to self-efficacy and captures the perceived ease, capability, or difficulty associated with implementing the silvopastoral system (Ajzen, 1991; Ajzen and Cote, 2008). We treat PBC as reflective construct. This leads to the hypothesis:

**H7**: PBC positively affects the intention to adopt SP

Farmers take decisions within the context of cultural and social influences (Burton, 2004; Ajzen, 1991). Subjective Norm (SN) refers to the social pressure the farmer perceives to implement or not implement a silvopastoral system (Ajzen, 1991). It is measured as a formative construct for the expectation of society, other farmers in the region, and family, and it is hypothesized to directly influence the adoption intention:

**H8**: SN affect the intention to adopt SP

Identity theory proposes that individuals hold multiple identities shaped by roles, groups, and social structures (Burke and Stryker, 2016). Self-identity (SI), often seen as internalized norms or values (Akerlof and Kranton, 2000), has been increasingly used in farmer behavior studies (van Dijk *et al.*, 2016; Oyinbo and Hansson, 2024; Zemo and Termansen, 2022). SI is relevant for understanding practices such as tree planting on agricultural land, which may conflict with cultural symbols and farmer identity (Burton, 2004; Warren *et al.*, 2016). In our study, SI reflects farmers' identification with the implementation of a silvopastoral system (van Dijk *et al.*, 2016), including enjoyment (Cullen *et al.*, 2018). We explore the inclusion of SI in the model selection stage to test the following hypothesis:

**H9**: SI affects the intention to adopt SP

# 3 Materials and Methods

## 3.1 Study design and questionnaire

Our questionnaire design, data collection, and model development involved a literature review on agroforestry perceptions in Europe and nine key informant interviews with experts from various disciplines and regions. These interviews complemented literature insights, helped us refine our model, and guided the design of a silvopastoral system tailored for cattle farmers. The questionnaire was pre-tested with farmers and researchers and pre-registered.

**Figure 2: Young silvopastoral system. © Philipp Weckenbrock. (left); Silvopastoral system with twenty-year-old black walnut trees. © Gabriel Pent. (right)**
Note: Further pictures were shown to respondents.

Respondents received a description of a modern silvopastoral agroforestry system suitable for Germany, featuring high-value timber and/or fast-growing wood planted in alleys on cattle pastures (Figure 2), and occupying about 5% of the pasture area. Respondents were informed that the described system qualifies as official agroforestry land use in Germany, allowing planting, harvesting, and removal while maintaining grassland status. Maintenance included protecting the trees from livestock, weed control, and removing lower branches on high-value timber trees. Harvest timelines were indicated as 10-20 years for fast-growing wood and 50-70 years for high-value timber.

To improve clarity and reduce understanding bias, instead of "silvopastoral system" we used the more common term "agroforestry system" in communication with the respondents. Respondents evaluated statements on a 5-point Likert scale (disagree–agree) and could opt not to answer. The outcome variable, *ImplementSP*, measured intention: "In the next 5 years, I plan to implement and manage an agroforestry system for timber production on pasture for cattle," rated on a 5-point Likert scale (very unlikely–very likely).

### 3.2 Study region and sampling

Our study area is Germany which introduced agroforestry as a land use category in 2023. We focus on silvopastoral systems with cattle-pasture-tree-interactions. This makes our target population about 62 200 German farms that hold cattle on pasture – about 58% of all farms that hold cattle in Germany in 2019/20 (Destatis, 2021d).

A market research institute recruited cattle farm managers who hold cattle on pasture across Germany through their database and through online publications in agricultural magazines. Due to data privacy restrictions, which did not allow us to sample from the whole of the target population, we opted for a convenience sampling method. We acknowledge that this leads to a sampling bias in unknown direction and limits statistical inference (Heckelei *et al.*, 2023). The target sample was 256 full submissions to be recruited within a time frame of six weeks in the beginning of 2024. Due to farmer protests during the recruitment period, the period was prolonged to eight weeks. The survey was closed with 204 full submissions.

### 3.3 Empirical modelling

The interactions depicted in the conceptual model (Figure 1) are analyzed via path analysis using Partial-Least-Squares Structural Equation Modelling (PLS-SEM). PLS-SEM is a non-parametric method which makes no assumptions on distributions, works efficiently with smaller sample sizes, and models with reflective and formative constructs (Hair *et al.*, 2018). The latent constructs in the measurement model are estimated using either reflective or formative measurement models. Reflective models are measured as composites of their indicators' common variance; formative models as linear combinations of their indicators (Esposito Vinzi *et al.*, 2010). We use formative models to study individual drivers of a construct. PLS-SEM estimates a sequence of partial regressions and aims to minimize the unexplained variance of the constructs in the structural model.

Answers are coded as missing when respondents preferred not to answer. We follow Hair *et al.* (2014) and remove observations with more than 15% missing indicator variables from the sample. Otherwise, missing values are replaced by the mean. We delete all observations with missing values in a robustness test.

To ensure model validity, we perform steps for model development and improvement based on Hair *et al.* (2018). We evaluate the convergent validity of formative constructs based on individual MIMIC models for each construct with reflective indicators, and evaluate the correlation coefficients. For reflective constructs, we evaluate the outer loadings, Internal Consistency, and Average Variance Extracted. To ensure that the reflective constructs are distinct from one another we evaluate the Heterotrait-Monotrait ratio (HTMT) between constructs. The structural model is assessed for collinearity using the criterion Variance-Inflation-Factor (VIF) < 3.

We apply mediation analysis to examine indirect paths (Venturini and Mehmetoglu, 2019). For formative constructs, we examine the contribution of individual indicators to their respective constructs based on their outer weights. This approach provides insights into the key drivers of the constructs and their influence within the model.

# 4 Results

## 4.1 Sample

Of the 204 survey submissions, 16 are excluded due to illogical answers, straightlining, or because more than 15% of the responses to socio-psychological model questions are missing. Another 14 are dropped as respondents managed fewer than ten cattle on pasture or less than one hectare of pastureland. The final sample therefore contains 174 observations (see Table 1).

**Table 1: Sample characteristics**

| Variable | Observations | Mean | Median |
|---|---|---|---|
| Number of cattle | 171 | 121.4 | 70.0 |
| Number of cattle on pasture | 171 | 82.1 | 50.0 |
| Total agricultural land area | 168 | 129.3 | 65.0 |
| Total pasture area | 168 | 38.3 | 18.5 |
| Total meadow area | 168 | 26.2 | 15.5 |
| Farmer age groups in years | | | |
| <35 | 173 | 0.19 | |
| 35-44 | 173 | 0.19 | |
| 45-54 | 173 | 0.23 | |
| 55-64 | 173 | 0.30 | |
| >64 | 173 | 0.09 | |
| Farmer has higher education degree | 174 | 0.36 | |
| Farm is a part-time farm | 173 | 0.33 | |
| Farm is an organic farm | 174 | 0.34 | |
| Farm has successor | 174 | 0.36 | |
| Farm succession not relevant, as it was just taken over | 174 | 0.34 | |
| Main farm branch is… | | | |
| Dairy | 174 | 0.51 | |
| Suckler cows | 174 | 0.19 | |
| Beef cattle | 174 | 0.13 | |
| Farm is located in the… | | | |
| East (former East German states) | 167 | 0.08 | |
| South (Bavaria, Baden-Württemberg) | 167 | 0.46 | |
| North-west | 167 | 0.46 | |
| Farm planted woody vegetation on pastures in the last five years (2019-2023) | 174 | 0.21 | |
| *ImplementSP* | | | |
| Very unlikely | 174 | 0.37 | |
| Unlikely | 174 | 0.28 | |
| Neutral | 174 | 0.27 | |
| Likely | 174 | 0.07 | |
| Very likely | 174 | 0.02 | |
| No answer | 174 | 0.00 | |

While detailed statistics on farms that hold cattle on pasture are unavailable, our sample aligns with the German farming population for age groups and part-time farming (Destatis, 2021a, 2021c) but oversamples higher-educated farm managers and organic farms (Destatis, 2021b, 2021c). Among respondents, 83% indicated that cattle farming is their primary activity, 51% hold dairy cows. The average farm size is 121 cattle, with most farms located in Bavaria and Lower Saxony. Approximately 9% of respondents express a likely or very likely intention to adopt silvopastoral systems. 33% express a likely or very likely intention to plant woody vegetation, but unlike the described system (e.g., an orchard meadow or a hedgerow).

The sampled farmers perceive positive animal welfare effects (see Table 2, mean: 4.2, median: 5) and benefits for cattle performance on hot days. However, labor and economic indicators are rated negatively. The fear related to policy and planning security of tree removal is highly skewed (mean: 4.5, median: 5).

## 4.2 Model selection

For model development, we use the outcome variable *ImplementSP* to capture the intention to adopt SP. We achieve convergent validity of all individual formative models ($\sigma > 0.70$) except for SN ($\sigma = 0.40$). We accept the low convergent validity of SN for our main model, but exclude SN in a robustness test. Using the conceptualized model in Figure 1 and PLS-SEM we remove for their low-loading due to collinearity. In PBC, we retain an indicator concerning knowledge that we consider important due to theory despite its low loading (Hair *et al.*, 2018). We exclude Attitude SP due to insufficient distinctiveness from SI and PAC (HTMT > 0.85).

The model's reflective constructs Attitude SLU, PBC, CC Risk Appraisal, and SI achieve internal consistency within the ideal range of 0.70-0.90 (Cronbach's alpha of 0.81, 0.71, 0.89, 0.87, respectively). All of their Average Variances Extracted as a measure of convergent validity are above the targeted minimum value of 0.50. We assess models with and without SI and select the model with SI based on the lower BIC value (BIC of -119.81 compared with -108.87 without SI).

**Table 2: Overview of indicators**

| Name | Indicators | Obs. | Mean | SD | Med. | Out. weight | Out. loading |
|---|---|---|---|---|---|---|---|
| **R: Climate Change (CC) Risk Appraisal** | | | | | | | |
| | If the current grazing system is maintained, it is likely that the effects of climate change on my farm over the next 10 years will ... | | | | | | |
| CCRA1 | ... threaten the profitability of the cattle farming operations on my farm. | 171 | 2.49 | 1.15 | 2 | 0.26 [0.22; 0.30] | 0.84 [0.78; 0.88] |
| CCRA2 | ... complicate the grazing of cattle. | 173 | 2.92 | 1.27 | 3 | 0.30 [0.27; 0.34] | 0.89 [0.85; 0.92] |
| CCRA3 | ... reduce the performance of cattle on pasture due to higher temperatures. | 173 | 3.23 | 1.17 | 3 | 0.30 [0.26; 0.33] | 0.89 [0.84; 0.92] |
| CCRA4 | ... reduce the yield security of pastures. | 174 | 3.44 | 1.18 | 4 | 0.30 [0.26; 0.34] | 0.86 [0.80; 0.90] |
| *CCRA5* | *... reduce the grassland yield of pastures. (removed)* | 174 | 3.39 | 1.21 | 3 | | |
| **R: Attitude towards single land use system (Attitude SLU)** | | | | | | | |
| | In general, I think that keeping the current grazing system would be .... | | | | | | |
| AttSLU1 | very bad - very good. | 172 | 3.95 | 0.72 | 4 | 0.32 [0.22; 0.39] | 0.88 [0.83; 0.92] |
| AttSLU2 | very disadvantageous - very advantageous. | 171 | 3.73 | 0.81 | 4 | 0.29 [0.17; 0.39] | 0.75 [0.60; 0.86] |
| AttSLU3 | very valuable - very useless. (reversed coding) | 173 | 4.03 | 0.75 | 4 | 0.32 [0.23; 0.43] | 0.82 [0.72; 0.89] |
| AttSLU4 | not risky at all - very risky. (reversed coding) | 171 | 2.64 | 0.91 | 3 | 0.32 [0.21; 0.43] | 0.75 [0.63; 0.84] |
| **F: Avoidance of Climate Change Adaptation (Avoidance)** | | | | | | | |
| AV1 | The effects of climate change are exaggerated. It is not necessary to adapt my farm during my operating years. | 173 | 2.39 | 1.14 | 2 | 0.89 [0.65; 1.03] | 0.95 [0.81; 1.00] |
| AV2 | If extreme weather events such as dry and hot periods increase, my farm will give up grazing. | 172 | 1.98 | 1.02 | 2 | -0.30 [-0.57; 0.04] | -0.43 [-0.68; -0.09] |
| AV3 | Extreme weather events are unpredictable. It is impossible to adapt my farm to potential future extreme weather situations. | 171 | 2.60 | 1.18 | 2 | 0.05 [-0.25; 0.36] | 0.31 [-0.06; 0.61] |

| Name | Indicators | Obs. | Mean | SD | Med. | Out. weight | Out. loading |
|---|---|---|---|---|---|---|---|
| **F: Perceived Efficacy (PE)** | | | | | | | |
| | The implementation and management of an agroforestry system with grazing would ... | | | | | | |
| PE1 | ... positively influence the well-being of the cattle, as the trees provide shade and protection from weather. | 173 | 4.17 | 1.09 | 5 | -0.00 [-0.19; 0.18] | 0.50 [0.34; 0.65] |
| PE2 | ... contribute to biodiversity conservation. | 172 | 3.77 | 1.22 | 4 | 0.20 [0.03; 0.36] | 0.63 [0.46; 0.76] |
| PE3 | ... reduce evaporation by providing shade and wind protection and, thus, improve the microclimate of the pasture. | 173 | 3.66 | 1.22 | 4 | 0.06 [-0.12; 0.24] | 0.60 [0.45; 0.73] |
| PE4 | ... contribute to maintaining the cattle's performance on warm days. | 173 | 3.79 | 1.18 | 4 | 0.02 [-0.17; 0.23] | 0.52 [0.38; 0.66] |
| PE5 | ... improve the nutrient and water balance of the soil through tree rooting. | 172 | 2.85 | 1.35 | 3 | 0.12 [-0.05; 0.26] | 0.62 [0.45; 0.75] |
| PE6 | ... be profitable for my farm. | 173 | 2.39 | 1.13 | 2 | 0.78 [0.59; 0.92] | 0.96 [0.89; 0.99] |
| *PEr* | *... contribute to the adaptation of my farm to climate change. (reflective indicator)* | 173 | 3.18 | 1.31 | 3 | | |
| **F: Perceived Adaptation Costs (PAC)** | | | | | | | |
| | When implementing and managing a grazed agroforestry system, ... | | | | | | |
| PAC1 | ... I have concerns about whether I would have enough pasture growth for my farm due to the loss of land and the shading. | 174 | 3.53 | 1.28 | 4 | 0.39 [0.17; 0.62] | 0.73 [0.53; 0.87] |
| PAC2 | ... I am concerned that the trees might not develop well. | 172 | 3.00 | 1.23 | 3 | 0.12 [-0.10; 0.33] | 0.44 [0.20; 0.64] |
| PAC3 | ... I fear that the trees could no longer be removed due to policy changes (e.g., declaration as landscape elements or biotopes). | 172 | 4.50 | 1.02 | 5 | -0.11 [-0.37; 0.13] | 0.45 [0.21; 0.65] |
| PAC4 | ... I have concerns about the amortization period. | 173 | 3.88 | 1.16 | 4 | 0.42 [0.17; 0.65] | 0.73 [0.54; 0.86] |
| PAC5 | ... I am concerned that the amount of labor required for pasture maintenance would increase significantly due to the tree alleys. | 172 | 4.28 | 1.10 | 5 | 0.51 [0.23; 0.74] | 0.80 [0.62; 0.90] |
| **F: Subjective Norms (SN)** | | | | | | | |
| SN1 | I have the impression that society expects me to adopt grazed agroforestry systems on my farm. | 169 | 2.14 | 1.24 | 2 | 0.60 [0.19; 0.86] | 0.60 [0.17; 0.86] |
| SN2 | My family would disapprove of me managing an agroforestry system. (reversed coding) | 162 | 3.36 | 1.36 | 3 | 0.84 [0.46; 1.06] | 0.79 [0.45; 0.96] |

| Name | Indicators | Obs. | Mean | SD | Med. | Out. weight | Out. loading |
|---|---|---|---|---|---|---|---|
| SN3 | Most farmers in my region would disapprove of me managing a grazed agroforestry system. (reversed coding) | 153 | 3.23 | 1.30 | 3 | -0.11 [-0.55; 0.33] | 0.20 [-0.25; 0.61] |
| *SNr* | *I think managing a grazed agroforestry system would enhance my reputation. (reflective indicator)* | 163 | 2.77 | 1.21 | 3 | | |
| **R: Perceived Behavioral Control (PBC)** | | | | | | | |
| PBC1 | It would be easy for me to set up and manage a grazed agroforestry system if I wanted to. | 174 | 2.68 | 1.29 | 2 | 0.33 [0.26; 0.40] | 0.77 [0.65; 0.84] |
| PBC2 | I have the knowledge and skills to implement and manage a grazed agroforestry system on my farm. | 174 | 3.32 | 1.31 | 3 | 0.25 [0.16; 0.32] | 0.62 [0.45; 0.74] |
| PBC3 | My farm has sufficient labor capacity to implement and manage a grazed agroforestry system. | 174 | 1.99 | 1.15 | 2 | 0.42 [0.33; 0.51] | 0.81 [0.73; 0.86] |
| PBC4 | The site conditions of the pastures on my farm are generally suitable for a grazed agroforestry system. | 174 | 2.95 | 1.36 | 3 | 0.35 [0.27; 0.44] | 0.72 [0.61; 0.81] |
| *PBC5* | *My operational conditions, e.g. tenancy agreements, make it difficult to implement and manage a grazed agroforestry system. (reversed coding) (removed)* | 171 | 2.27 | 1.45 | 2 | | |
| *PBC6* | *It would be easy for my farm to sell the timber at a profit. (removed)* | 171 | 2.70 | 1.19 | 3 | | |
| **R: Self-identity (SI)** | | | | | | | |
| SI1 | Agroforestry systems fit my farm's operational goals. | 172 | 2.74 | 1.32 | 3 | 0.42 [0.39; 0.46] | 0.91 [0.88; 0.93] |
| SI2 | Agroforestry systems are not for me. (reversed coding) | 169 | 3.32 | 1.34 | 4 | 0.35 [0.31; 0.38] | 0.89 [0.84; 0.92] |
| SI3 | I would enjoy implementing and managing a grazed agroforestry system. | 172 | 3.04 | 1.25 | 3 | 0.36 [0.32; 0.39] | 0.87 [0.81; 0.91] |
| *SIr* | *I think that planting trees is not the job of agriculture. (reversed coding) (removed)* | 169 | 3.98 | 1.08 | 4 | | |
| **R: Attitude towards silvopastoral system (Attitude SP)** | | | | | | | |
| | In general, I think that the implementation and management of a grazed agroforestry system on my farm would be .... | | | | | | |
| AttSP1 | very useless - very valuable. | 174 | 3.12 | 1.00 | 3 | | |
| AttSP2 | very advantageous - very disadvantageous. (reversed coding) | 174 | 2.79 | 1.02 | 3 | | |
| AttSP3 | very bad - very good. | 174 | 3.16 | 0.94 | 3 | | |
| AttSP4 | not risky at all - very risky. (reversed coding) | 171 | 3.36 | 0.91 | 3 | | |

| Name | Indicators | Obs. | Mean | SD | Med. | Out. weight | Out. loading |
|---|---|---|---|---|---|---|---|
| **Perceived Vulnerability** | | | | | | | |
| *PV1* | *My cattle farming business has suffered financial losses due to extreme weather events in the last six years (2018-2023). (used for Assessment of Convergent Validity of "Avoidance" construct)* | 174 | 3.10 | 1.39 | 3 | | |
| *PV2* | *My farm income is heavily dependent on my current grazing system. (not used)* | 173 | 2.77 | 1.35 | 3 | | |
| *PV3* | *The probability that I will be able to maintain my current grazing system in the future is very high. (reversed coding) (used for Assessment of Convergent Validity of "Avoidance" construct)* | 174 | 2.17 | 1.11 | 2 | | |

Note: percentile 95% confidence intervals in squared brackets are based on bootstrapping using 5 000 subsamples. Outer weights and outer loadings of the empirical base model. R denotes a reflective measurement model and F a formative measurement model. Except for the attitude indicators and outcome variables, all the indicators were asked on a 5-point Likert scale (disagree – agree).

## 4.3 PLS-SEM results

Figure 3 illustrates the empirical model with estimates of the standardized direct path coefficients (β), the respective 95% confidence intervals (CI) and $R^2$-values based on PLS-SEM. We interpret the CI as compatibility intervals that indicate how compatible our data and findings are with the model and hypotheses (Amrhein, Greenland and McShane, 2019). The $R^2$ and adj.-$R^2$ of *ImplementSP* (0.61 and 0.59, respectively) can be considered moderate (Hair *et al.*, 2018).

In the appraisal of the SLU, the wide confidence interval including zero suggest that a direct link between CC Risk Appraisal and *ImplementSP* (H1) is not compatible with our sample. Likewise, H2, mediation through Avoidance, is not compatible with our sample. Mediation analysis reveals complete mediation of CC Risk Appraisal via Attitude SLU suggesting that H3 is compatible with our data. A one standard deviation (SD) increase in Climate Change Risk Appraisal alters Attitude SLU by -0.28 SD. In turn, lower Attitude SLU is associated with a higher intention to adopt SP (β = -0.17). Farmers who perceive a higher risk of climate change attribute a higher efficacy to SP (β = 0.44), which supports H10.

Within the technical appraisal of SP, we find that our sample is compatible with H4, H5, and H7. Farmers who perceive a higher efficacy of silvopasture (PE) and a higher capability of implementing it (PBC), have a higher intention to implement a modern silvopastoral system (β = 0.25 and 0.19, respectively). Farmers who perceive higher adaptation costs (PAC) have a lower intention to implement (β = -0.18). Our sample is also compatible with H11 (β = -0.55). In the social appraisal, a one SD increase in the construct value of SI is associated with a 0.32 SD increase in *ImplementSP*. This result is in line with H9 and represents the largest path coefficient. Our sample is not compatible with H8.

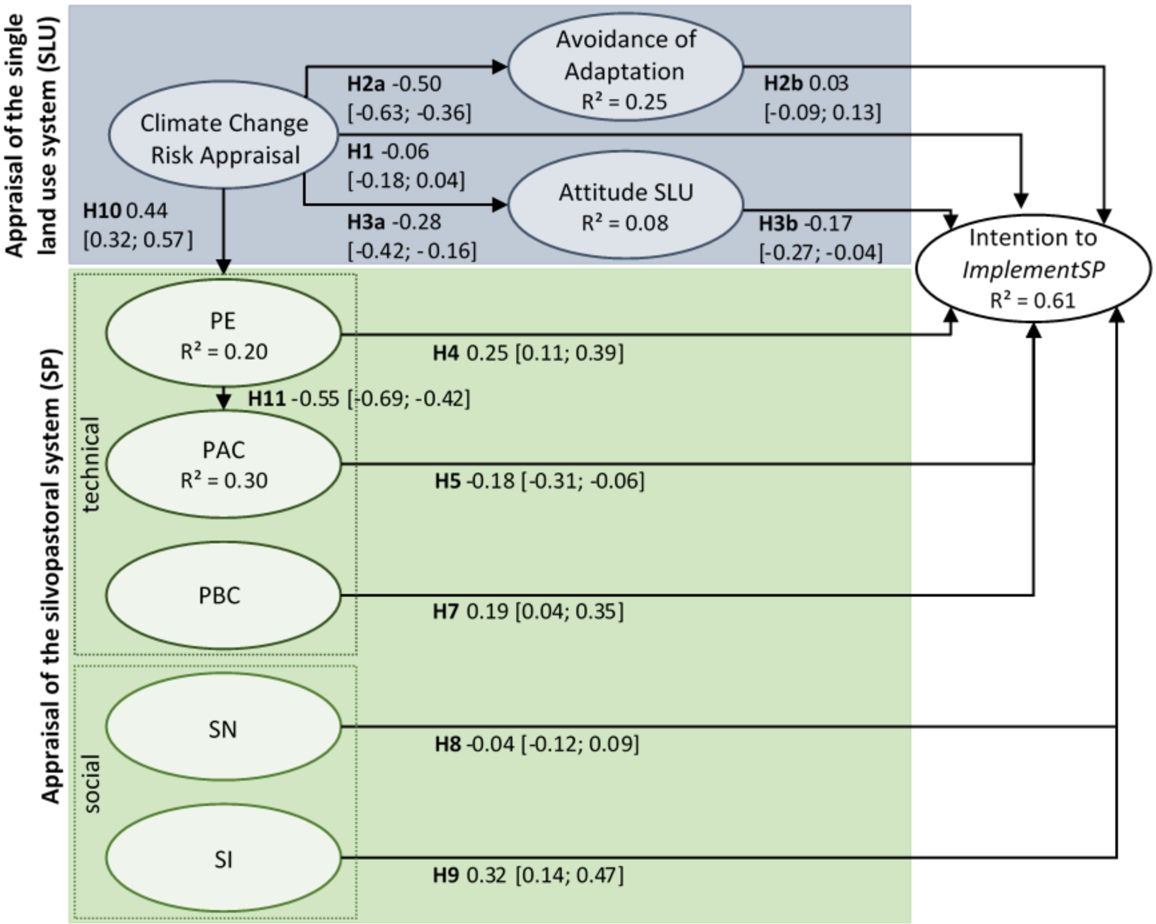


**Figure 3: PLS-SEM path coefficients and 95% confidence intervals for the empirical base model estimating the intention to adopt a modern silvopastoral system (*ImplementSP*)**
Note: percentile 95% confidence intervals in squared brackets are based on bootstrapping using 5 000 subsamples. The BIC of this model is -119.81 and the adj.-$R^2$ of intention 0.59.

The outer weights and outer loadings of the final model are shown in Table 2. For our sample, we only find a reliable association of the formative constructs PE and PAC with *ImplementSP*. Whenever the 95% CI of an indicator's outer weights do not include zero, we conclude that it makes a reliable contribution to the construct. For the construct PE, reliable contributions are made by PE2 (contribution to biodiversity conservation; 0.20) and PE6 (profitability; 0.78), with the latter contributing most to the construct. In contrast, animal welfare improvement (PE1) and maintenance of cattle performance (PE4) do not reliably contribute to the construct. For the construct PAC, reliable contributions are made by the concern about required labor (PAC5; 0.51), the amortization period (PAC4; 0.42) and pasture growth (PAC1; 0.39).

**Table 3: Robustness checks**

| Paths | Exclusion of negative outer weights (1) *ImplementSP* Coef. | SD | 95%-CI Lower | 95%-CI Upper | Exclusion of construct SN (2) *ImplementSP* Coef. | SD | 95%-CI Lower | 95%-CI Upper | Listwise deletion of missing (3) *ImplementSP* Coef. | SD | 95%-CI Lower | 95%-CI Upper |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CC Risk Appraisal → Intention | -0.05 | 0.06 | -0.16 | 0.05 | -0.06 | 0.06 | -0.18 | 0.04 | -0.06 | 0.07 | -0.21 | 0.07 |
| CC Risk Appraisal → AV | -0.47 | 0.07 | -0.60 | -0.33 | -0.50 | 0.09 | -0.63 | -0.36 | -0.52 | 0.11 | -0.66 | -0.35 |
| AV → Intention | 0.06 | 0.06 | -0.05 | 0.16 | 0.03 | 0.05 | -0.08 | 0.13 | -0.00 | 0.07 | -0.14 | 0.12 |
| CC Risk Appraisal → Attitude SLU | -0.28 | 0.07 | -0.42 | -0.16 | -0.29 | 0.07 | -0.42 | -0.16 | -0.29 | 0.07 | -0.44 | -0.15 |
| Attitude SLU → Intention | -0.16 | 0.06 | -0.28 | -0.04 | -0.16 | 0.06 | -0.27 | -0.04 | -0.18 | 0.07 | -0.31 | -0.04 |
| PE → Intention | 0.25 | 0.07 | 0.11 | 0.40 | 0.25 | 0.07 | 0.11 | 0.39 | 0.24 | 0.09 | 0.07 | 0.41 |
| PAC → Intention | -0.18 | 0.06 | -0.31 | -0.05 | -0.17 | 0.06 | -0.31 | -0.06 | -0.19 | 0.08 | -0.36 | -0.06 |
| PBC → Intention | 0.20 | 0.08 | 0.05 | 0.35 | 0.19 | 0.08 | 0.04 | 0.35 | 0.19 | 0.09 | 0.02 | 0.37 |
| SN → Intention | -0.04 | 0.05 | -0.14 | 0.07 | | | | | -0.07 | 0.07 | -0.17 | 0.09 |
| SI → Intention | 0.32 | 0.09 | 0.15 | 0.49 | 0.31 | 0.08 | 0.14 | 0.46 | 0.31 | 0.10 | 0.09 | 0.49 |
| CC Risk Appraisal → PE | 0.44 | 0.06 | 0.32 | 0.57 | 0.44 | 0.06 | 0.32 | 0.57 | -0.06 | 0.07 | -0.21 | 0.07 |
| PE → PAC | -0.54 | 0.07 | -0.69 | -0.40 | -0.55 | 0.07 | -0.69 | -0.42 | -0.56 | 0.08 | -0.71 | -0.41 |
| N | 174 | | | | 174 | | | | 133 | | | |
| Adj.-$R^2$. of Intention | 0.62 | | | | 0.60 | | | | 0.56 | | | |
| BIC | -120.62 | | | | -124.54 | | | | -73.45 | | | |

Note: Percentile 95%-confidence intervals (CI) are based on bootstrapping using 5 000 subsamples. Listwise deletion deletes all observations with at least one missing value in the included variables.

The results remain robust in selected robustness tests shown in Table 3. Table 4 depicts a simple model based on the constructs of the Theory of Planned Behavior. The results support alternative hypotheses for the association of Attitude SP (β = 0.47) and PBC (β = 0.31) with *ImplementSP*, while we fail to find an association with SN based on our sample. The adjusted $R^2$ decreases and the BIC increases compared to our model.

Table 4: Model of Theory of Planned Behavior

| | *ImplementSP* | | | |
|---|---|---|---|---|
| Paths | Coef. | SD | 95%-CI | |
| | | | Lower | Upper |
| Attitude SP → Intention | 0.47 | 0.07 | 0.32 | 0.59 |
| PBC → Intention | 0.31 | 0.08 | 0.14 | 0.46 |
| SN → Intention | 0.02 | 0.06 | -0.08 | 0.16 |
| N | 174 | | | |
| Adj.-$R^2$. of Intention | 0.50 | | | |
| BIC | -104.18 | | | |

Note: Percentile 95%-CI are based on bootstrapping using 5 000 subsamples.

## 5 Discussion

Research on the adoption of agri-environmental and climate adaptation measures highlights the importance of considering farmer behavior and perceptions (Huber *et al.*, 2024; Schaub *et al.*, 2023; van Valkengoed and Steg, 2019). Our findings are in line with other studies suggesting that identity-related factors are strongly associated with agroforestry and in particular also silvopasture adoption intentions (Felton *et al.*, 2023; Irwin *et al.*, 2023). The absence of subsidies in our study description may amplify the role of intrinsic motivation, measured by the construct of SI (Lokhorst *et al.*, 2011; van Dijk *et al.*, 2016).

Within the technical appraisal of the silvopastoral system, PE, PAC, and PBC are moderately associated with the intention to adopt. While most farmers perceive that silvopasture would increase animal well-being on pastures, the most important drivers for the intention to adopt within PE and PAC are related to biodiversity conservation, profitability, and complexity of pasture management. PBC captures the farmer’s own capability as well as external factors that support or inhibit adoption. Unlike previous studies with cattle farms that find no association between PBC and silvopasture adoption intentions (Irwin *et al.*, 2023; Opdenbosch and Hansson, 2023), we observe a positive association. The results of the technical appraisal underscore the importance for respondents to understand the system and its implications in the survey setting.

The appraisal of the current pasture system is less strongly associated with adoption intention. We find no direct association of farmers' CC Risk Appraisal with intention. Our results align with studies applying the Protection Motivation Theory, where the "threat appraisal" has often been found to have limited behavioral influence (Norman, Boer and Seydel, 2015). Similarly, awareness of climate change effects often only has a limited influence on adopting mitigation or adaptation measures (Stahlmann-Brown, Swerdloff and Wesselbaum, 2024; Li *et al.*, 2017). However, our results show that CC Risk Appraisal indirectly influences the intention through farmers attitudes towards keeping the current land use system (Attitude SLU) and PE. Thus, the inclusion of mediations in our model, improves our understanding of how climate change perceptions influence intentions indirectly.

Our results suggest that Attitude SP, a key construct in the Theory of Planned Behavior, is already captured by other constructs in our model, in particular PAC and SI. As suggested by Sok *et al.* (2021), we compare a model with only the three constructs of the Theory of Planned Behavior with our extended model which decreases the in-sample predictive power (adj.-$R^2$ = 0.50 compared with adj.-$R^2$ = 0.59). Our sample size is insufficient to detect smaller effects. We were not able to reliably estimate the associations between intention to adopt and the constructs Avoidance of Climate Change Adaptation and SN. Studies in Belgium and Ireland similarly report no influence of social or group pressure on adoption intentions (Borremans *et al.*, 2016; Irwin *et al.*, 2023).

Farmers in our sample were concerned that a policy change may hinder the later removal and commercial usage of the trees. This can be explained by past experience such as a regulatory change that declared orchard meadows to be protected biotopes (BNatSchG, 2022) and the sudden repeal of a fuel subsidy to German farmers in December 2023 that triggered widespread farmer protests during the data collection period (Finger *et al.*, 2024). For this reason, this indicator may have been overestimated in our study. As the removal of this indicator does not change the results or improve our empirical model (see Table 3 model (1)), we retain it in the main model. Similarly, widespread agreement with and, thus, low response variance regarding perception of benefits for cattle welfare limits the reliability of our estimates of the association between this perception and the intention to adopt. Weighing of the agreement of formative indicators with the importance of this factor for farm decision-making as suggested by Ajzen (1991) could increase response variance, and, thus, reliability.

The study's design focused on a silvopastoral system that integrates wood and timber use for productive purposes. This specific system might not align with the preferences of all farmers. While this specificity allowed for more reliable evaluations, it limits the generalizability of our results to other types of silvopastoral systems. 9% of our sample consider planting a similar system, however, 33% consider planting other woody vegetation in cattle pasture, for example hedgerows or orchard meadows.

Finally, the non-random sampling technique may have introduced selection bias, as farmers who are more inclined to adopt silvopastoral systems might also have been more likely to complete the survey. Given that 23% of farmers in our sample had already planted woody vegetation on pastures in the past five years, these results might not fully reflect broader farmer populations. Furthermore, as intention is not always followed by actual adoption of the behavior (Hennessy, Kinsella and Thorne, 2016; van Dijk *et al.*, 2016) the results should be interpreted with care.

Our findings are important for policies aimed at promoting the adoption of silvopastoral systems. While silvopastoral systems may not be suitable for all regions, for instance those with vulnerable species reliant on open landscapes, they offer important potential for enhancing agricultural sustainability and biodiversity in appropriate contexts. They should be regarded in the context of climate change adaptation, a widespread desire for grazing cattle (Risius and Hamm, 2017), and the creation of resilient, biodiverse landscapes.

# 6 Conclusion

This study explores how the perceptions and intentions of cattle farmers in Germany influence their intentions to adopt silvopastoral systems. Our findings indicate that farmers' identification with silvopastoral systems (Self-identity), beliefs about biodiversity conservation, concerns about the profitability and pasture management of silvopastoral systems as well as the farms perceived capability (Perceived Behavioral Control) of adopting such a system are the primary drivers of adoption intentions. To encourage the adoption of productive silvopastoral systems, policies should address economic concerns and potential economic benefits, e.g. through carbon sequestration certificates (Thiesmeier and Zander, 2023).

Cattle farmers recognize potential benefits from silvopastoral systems for climate change adaptation, such as enhancing cattle welfare on pasture, maintaining cattle performance on warmer days, and improving pasture microclimates. While we find no direct association of farmers' Climate Change Risk Appraisals (CC Risk Appraisal) with their intention to adopt, we observe indirect effects through farmers' attitudes towards keeping their current land use (Attitude SLU) and perceived benefits of silvopastoral systems compared to the current land use (PE). The inclusion of the appraisal of the current pasture system and mediating effects enhances the explanatory power of our model.

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