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A window of opportunity? Understanding silvopasture adoption of grassland-based cattle farms through the Multi-level Perspective

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Abstract

European grassland-based cattle farms (GBCF) are facing increasing pressures from climate change, biodiversity loss, and economic uncertainty. Agroforestry practices, such as establishing silvopastoral systems, offer potential to strengthen the resilience of these farms. However, the enablers and barriers to adopting silvopasture on European dairy and beef GBCF remain under-researched. This study addresses this gap by appraising how perceived opportunities and risks, together with policy and structural conditions, shape farmers' adoption decisions in the context of the Common Agricultural Policy (CAP) 2023–2027 reforms in Germany. Using the multi-level perspective framework and drawing on ten semi-structured expert interviews and a survey of 187 farms that graze cattle, we find that macro-level pressures are increasing farmers' willingness to adopt innovations under uncertainty. Our results further suggest that silvopasture adoption under the new CAP scheme is driven by a mix of economic and intrinsic motivations, particularly among farms that graze cattle. Key adoption barriers include high management complexity, long time horizons until direct financial returns from trees materialize, knowledge deficits, and policy distrust. By highlighting how the agroforestry diffusion process and farmers' decision-making are embedded in broader socio-technical and policy contexts, this study advances the applied sustainability transitions literature and contributes to a deeper understanding of silvopasture adoption mechanisms in Europe.

JEL-codes: O33, Q15, Q18, Q55

Keywords: agroforestry adoption, silvopastoral systems, multi-level perspective (MLP) framework, socio-technical transitions, climate change adaptation, grassland-based cattle farms

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1 Introduction

European grassland-based cattle farms (GBCF)[1] face growing pressures from climate change, biodiversity loss, and evolving socio-economic and regulatory conditions. Grassland productivity has increased in past decades through intensification. However, this often comes at the expense of other ecosystem services and biodiversity (Schils et al. 2022). Livestock farming produces substantial greenhouse gases and nutrient emissions, notably nitrogen and phosphorus (Leip et al. 2015). Consumer concerns about animal welfare and adverse health impacts of meat-heavy diets are also affecting demand for livestock products and driving interest in plant-based alternatives (Marcus et al. 2022, Ammann et al. 2024). Consumers prefer products from systems where livestock graze on pastures, which they associate with natural husbandry, rather than pure confinement systems (Schulze et al. 2021). Organic farms face additional regulatory pressures, as exceptions to mandatory pasture access for cattle will no longer be admissible in Germany from 2025 under the EU organic regulation. Climate change further affects forage yield and quality, increases drought risk, and heightens heat stress for cattle (Chang et al. 2017, Hempel et al. 2019).

As a result, GBCF need to adapt to changing environmental and social conditions. In this context, integrating trees into meadows, and especially in pastures, as in silvopastoral systems, offers a promising adaptation strategy to increase biodiversity, animal comfort, and grassland resilience (Wreford and Topp 2020, Amorim et al. 2023, Hernández-Morcillo et al. 2018, McAdam and McEvoy 2008). This is because trees provide shade and act as wind barriers, which helps balance grassland microclimates, while cattle naturally seek shade to alleviate discomfort from solar radiation and heat. (Polsky and von Keyserlingk 2017). Though one hectare of silvopasture generates less wood or forage than one hectare of forest or grassland, respectively, the overall land productivity increases (Pent 2020). In addition, leaf fodder can be offered as additional fodder with high nutritive value for ruminants (Vandermeulen et al. 2018).

Despite the potential of silvopastures for GBCF, factors that enable or hinder their adoption as a transformative practice within established livestock production systems remain poorly understood. This study addresses this gap by examining expert perceptions of opportunities, risks, and challenges that arise from framework conditions and are associated with implementing silvopastures a niche-innovation and resilience strategy for German grassland-based dairy or beef cattle farms. We explore how the wider socio-technical context and perceived attributes of silvopastoral systems shape farmers' motivations and adoption decisions.

[1] We define grassland-based cattle farms as cattle farms that rely on forage from (permanent) grasslands for feed. If applicable, we differentiate between grazed pastures and non-grazed meadows as well as farms that graze cattle as opposed to farms that do not graze cattle.

Silvopastoral systems are the most common type of agroforestry system in Germany, however, their extent more than halved between 2012 and 2022 (Rubio-Delgado et al. 2025). Traditional agroforestry systems, such as orchard meadows and hedgerow systems, have been declining for decades, driven by agricultural mechanization, urbanization, and adverse policies that encouraged their removal (Eichhorn et al. 2006, Plieninger et al. 2015). This trend, alongside rising awareness of their notable biocultural values, has led to enhanced protection and subsidies for maintaining traditional systems. In addition, European and national-level agroforestry associations have been formed to foster stakeholder exchange and promote adoption of new agroforestry systems.

In 2023, Germany introduced an agroforestry scheme through the European Union Common Agricultural Policy (CAP) 2023-2027, setting a framework for the planting and harvest of woody vegetation on agricultural land (BMEL 2022). Under this scheme, trees can be planted either dispersed – with 50-200 trees per hectare – or in rows covering up to 40% of the plot area, facilitating machine maintenance of the grassland. Woody vegetation from such systems serves economic purposes, which differs from traditional systems, where usage is often limited and removal often prohibited (Klimke et al. 2025). An agroforestry maintenance subsidy ("Eco-scheme 3") accompanies the scheme, however, stipulates additional requirements, such as specific planting distances between tree rows and to field and forest edges (BMEL 2022). Low adoption led to a simplification of requirements and higher premiums, from €60/ha wooded area in 2023 to €200/ha for the years 2024-2025, with a target of €600/ha announced in 2025 (BMEL 2024a, 2024b, Ministerium für Ernährung, Ländlichen Raum und Verbraucherschutz 2025).

Previous research highlights the importance of socio-ecological feedback (Klimke et al. 2025) and legal barriers (Klimke et al. 2024) to implementing the new agroforestry scheme in Germany. Whereas these studies approach agroforestry broadly – without distinguishing specific system types – our work narrows in on silvopastoral practices and their adoption on GBCF. By focusing on this system type, our study pays heed to a need to better account for farmers' heterogeneous production circumstances to further agronomic innovations that fit their contextual realities (Sinclair and Coe 2019). Complementing Klimke et al.'s (2025) analysis of legal and institutional "lock-ins", our study provides a socio-technical system and actor-centered perspective on agroforestry adoption that highlights experts' perceptions of key factors that shape cattle farmers' decision-making contexts.

Our mixed-methods study, combining expert views with farm survey insights, draws on the Multi-Level Perspective (MLP) framework (Geels 2011, 2002, Kemp et al. 1998, Rip and Kemp 1998) for analyzing socio-technical transitions. We focus on interactions across three system levels: the socio-technical landscape as the external macro-level context, the socio-technical regime as the proximate context of the innovation, and niche-innovations. Situating farmers' adoption decisions within this dynamic framework allows us to assess how external shocks and macro-level changes, such as climate impacts and new policies, open windows of opportunity for silvopastoral uptake. Moving beyond a purely barrier-focused perspective, we also appraise perceived risks and opportunities that affect farmers' adoption decisions. Our inquiry is guided by three research questions:

1. How do socio-technical landscape-level pressures, including climate change, challenge the established cattle farming regime in Germany?
2. Which opportunities, risks, and challenges do experts associate with silvopastoral systems as niche-innovations for this regime?
3. Which factors motivate cattle farmers' adoption of silvopastoral systems?

2 Theoretical framework

The Multi-level Perspective (MLP) framework provides a heuristic for analyzing how innovations targeted at increasing the sustainability or resilience of food systems emerge, integrate into, or transform existing land-use and food systems (Elzen et al. 2011, Geels 2011, 2019). The MLP distinguishes three system levels (socio-technical landscape, socio-technical regime, and niches), with higher levels exhibiting greater structural stability (Geels 2011). Alignment of pressures and opportunities within and across these levels can open windows for change, broader adoption, transformation, or even substitution of technologies (Elzen et al. 2011, Geels 2011). The MLP integrates agency in the form of bounded rationality, including trial-and-error learning (Geels 2011).

The *socio-technical landscape*, the highest level, captures the external context and macro-level trends, such as climate change, demographic change, and norms that affect emerging innovations and the established regime (Geels 2011, Rip and Kemp 1998). Landscape-level challenges stimulate the search for innovative solutions and drive technological advancements (Rip and Kemp 1998).

The *socio-technical regime*, the medium-level, depicts the currently dominant structures and practices in the proximate context of an innovation, i.e., cattle farming in Germany. It is composed of sub-regimes (i.e., socio-cultural, policy, and science). Each sub-regime has its own actors, resources, shared rules, and institutions, such as regulations, beliefs, knowledge, and practices, stabilizing the regime (Geels 2011, Mylan et al. 2019). Actors maintain or incrementally improve elements of the regime, and sub-regimes co-evolve with each other (Geels 2019, 2011).

Niches, the lowest level, are protected spaces for innovations that emerge when actors see unmet needs within the dominant socio-technical regime (Geels 2011). Even if short-term returns seem negative, actors may invest in new technologies based on beneficial future expectations (Rip and Kemp 1998). In niches, innovations develop under controlled selection pressures, supported by adaptation, learning, and network-building (Rip and Kemp 1998, Geels 2019). Niche-innovations can eventually merge into the existing regime or help create a new one, gaining momentum when expectations stabilize, networks expand, and influential actors get involved (Geels 2011, Rip and Kemp 1998). Niche actors, including policymakers, can develop niches by adjusting rules, moderating interactions, and monitoring emerging needs or problems (Kemp et al. 1998).

Agri-food system regimes with their many producers and consumers, but few processors and retailers, are more loosely structured and flexible than those of other sectors (Mylan et al. 2019). Nevertheless, they remain constrained by path dependencies, reinforced through various types of lock-ins, i.e., self-reinforcing mechanisms that stabilize existing systems and impede change, leading to mostly incremental changes and innovations (Geels 2019). These lock-ins can be cognitive (i.e., established ways of thinking without considering alternatives), social (i.e., shared norms and peer expectations), techno-economic (i.e., cost structures, sunk investments, and market dependencies), and institutional (i.e., rules and policies) (Geels 2019, Weituschat et al. 2022).

The MLP is often used to analyze innovation diffusion and transformation processes ex-post (Mylan et al. 2019). Here, in contrast to such retrospective studies, we use the framework to explore ongoing landscape, regime, and niche dynamics that affect the adoption of silvopastoral systems in Germany. In this context, niche actors include pioneering farmers, advisory services, associations, and policymakers.

3 Material and Methods

We apply a mixed-methods approach combining two data types: qualitative data, capturing perceptions of challenges and appraisals of agroforestry systems in the new regulatory context derived from interviews with ten German agroforestry, grassland, and animal husbandry experts; and quantitative data from a survey with 187 German farmers with grazing cattle, for complementary insights on adopted climate change adaptation measures and woody vegetation on farms.

3.1 Qualitative interviews and analysis

We conducted semi-structured interviews with ten key informants from June to October 2023. We identified the informants via an internet search for agroforestry services in Germany, through contacting state extension offices, and snowball sampling. We did not target a specific region; however, most interview partners had some regional expertise, with southeastern and central Germany as the main areas covered. The recruited interviewees were affiliated with agricultural state offices/extension service (n=5), scientific institutions (n=3), and private organizations (n=2). Due to their positions between practice and research or from research they act as knowledge multipliers and their backgrounds offer diverse perspectives on silvopasture adoption in Germany – complementary to those of farmers (compare 3.2). Their expertise spanned agroforestry and forest grazing (n=4), grassland management (n=2), animal systems (n=2), and agri-environmental subsidies (n=1) (see Table A1 in the annex).

Our interview guide (see Table A2 in the annex) addressed two main themes: The first part focused on challenges, risks, and adaptation strategies for GBCF. We asked the interviewees to specifically focus on challenges related to markets and prices, policies and regulations, climate change, biodiversity, and production.

The second part captured perceived opportunities, risks, motivations, and challenges for silvopasture adoption. In the interviews, we used the following definition for silvopastoral systems: “a land-use system in which woody plants (trees and shrubs) are combined with livestock farming on the same area to benefit from ecological and economic interactions. In the following, we are interested in silvopastoral systems for food, fodder, and timber production, but not as short rotation coppice systems for energy wood. This means in particular fruit or nut trees and shrubs, high-value timber and fodder hedges on grassland.”

We shared the interview guide with the participants prior to the interviews to create a transparent and comfortable interview setting and enable the interviewees to familiarize themselves with the topics covered. During the interviews, more emphasis was put on the first or second part, respectively, depending on the interviewee’s expertise. The forest grazing expert only received questions on risks and opportunities of forest grazing, and on farms engaged in this practice. Interviews with nine interview partners were conducted via video conferences, recorded with participants’ consent, and subsequently transcribed. One interview was conducted via telephone, taking detailed notes. All transcriptions and notes were approved by the interviewees for further analysis.

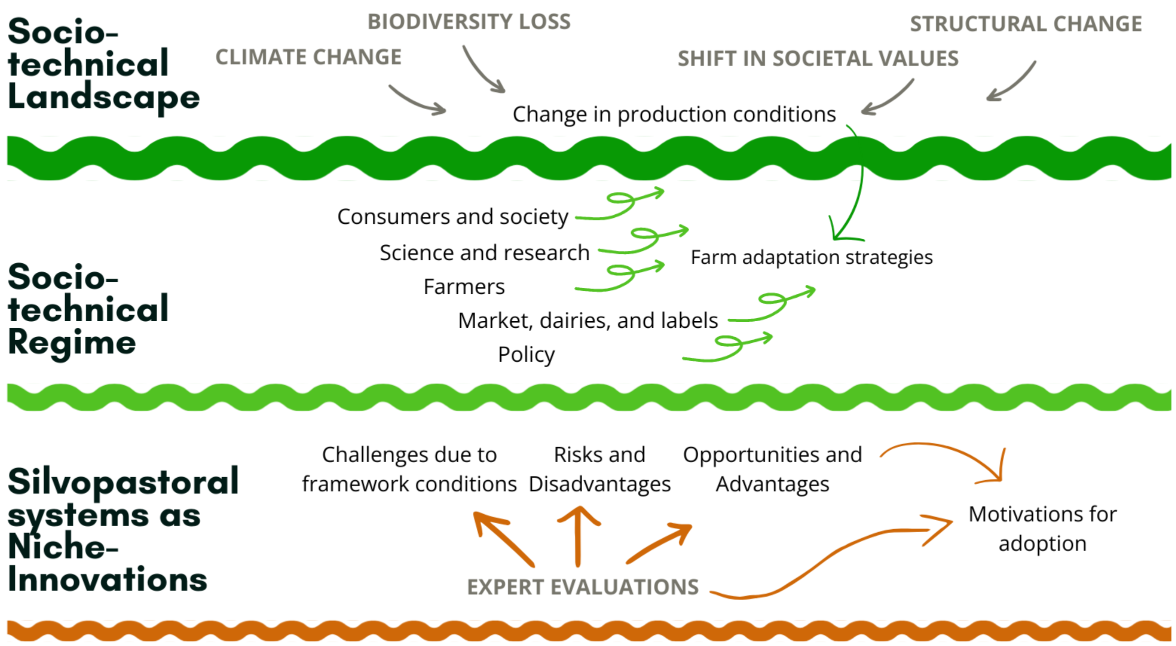

Figure 1: Coding framework based on the Multi-level Perspective framework, adapted from Geels (2011, 2002).

We used the software f4x (2023) for transcriptions, making manual adjustments for intelligent verbatim. The subsequent coding drew on Rädiker and Kuckartz's (2020) methodology for systematic and focused interview analysis using the MAXQDA software (2024). The MLP was introduced at the coding stage and guided our coding framework (Figure 1). We combined deductive codes, reflecting the three MLP levels (including sub-regimes, e.g., "research" or "society"), with inductive codes, to develop sub-themes capturing evaluations of silvopastoral systems and motivations for their adoption. All interviews were initially coded by the first author. Subsequently, the second author double-coded three interviews to assess intercoder agreement. We resolved identified discrepancies by refining the coding framework before recoding the interviews.

3.2 Farm survey and analysis

The survey of 204 German farmers with cattle on pasture was implemented between January and March 2024. It was part of a project focused on future pasture systems, with most questions focusing on farmer perceptions of a specific silvopastoral system to analyze adoption intentions (Pallauf et al. 2025). Questions included in the present study, to complement insights from the expert interviews, targeted implemented climate change adaptation measures related to cattle farming, the prevalence of woody vegetation in pastures and meadows, and farmers' ranking of reasons for why they would include woody vegetation in their pastures. A market research institute recruited the respondents, following a convenience sampling strategy due to data privacy restrictions for farms in Germany. This likely introduced a bias towards farmers more open to silvopasture.

During data cleaning, we removed 17 observations because of illogical answers or non-differentiation in ratings, resulting in a final sample of 187 farms. We analyzed the survey data using descriptive tables and reported t-statistics where appropriate. In addition, we constructed a network graph to visualize the reported bilateral co-occurrence of climate change adaptation measures on farms. Farmers were also asked to rank up to five of 19 possible purposes for integrating woody vegetation in pastures, with the first rank indicating the highest importance. Alongside the share of farmers selecting each purpose, we report the average rank score and attribute the purpose to an ecosystem service. In addition, we provide results of a rank-ordered logit choice model.

The average farm in our sample (Table 1) had 121 cattle aged six months or older. Averaged across the entire sample, 79% of cattle on a farm had access to pasture. Cattle farming was the primary activity for 80% of the respondents, and 48% held dairy cows as their main farming activity. Our sample aligns well with the general German farming population for age groups and part-time farming (Destatis 2021a, 2021c), and the main cattle meat and milk producing areas in Germany, although we oversampled farm managers with higher-education degrees (Destatis 2021b).

Table 1: Sample characteristics

Variable	Observations	Mean	Median
Number of cattle on farm	184	121.2	70
Share of grazing cattle as of total number of cattle	184	0.79	1
Total agricultural land area (ha)	181	136.7	65
Total pasture area (ha)	181	38.3	15
Total meadow area (ha)	181	25.7	15
Farmer age groups in years			
<35	186	0.18	
35-44	186	0.19	
45-54	186	0.23	
55-64	186	0.31	
>64	186	0.09	
Farmer has higher education degree	187	0.36	
Farm is a part-time farm	185	0.32	
Farm is an organic farm	187	0.34	
Farm succession			
Farm has designated successor	187	0.36	
Farm succession is not yet deemed relevant	187	0.35	
Farm succession is pending	187	0.23	
Farm is terminated	187	0.06	
Main farm activity			
Dairy	187	0.48	
Suckler cows or beef cattle	187	0.32	
Farm location			
East (former East Germany)	180	0.08	
South (Bavaria, Baden-Württemberg)	180	0.47	
North-west	180	0.44	
Grazing systems			
Rotational grazing	185	0.70	
Stand pasture	185	0.50	
Jogging pasture	185	0.28	

Note: unless otherwise indicated, variables are coded 1 if the answer is 'yes' and 0 otherwise. Number of cattle includes cattle aged six months or older. Multiple choices were allowed on the question on grazing systems.

4 Results

4.1 Challenges for grassland-based cattle farms

4.1.1 Identified landscape-level pressures

The interviewed experts perceived multiple landscape-level pressures that GBCF, in particular those with grazing cattle, face or are expected to experience in the future:

Climate change triggers a perceived need for adaptation on German GBCF, as it is expected to lead to an increase in extreme weather events, including heavy rainfall, dry spells, and summer droughts. For climate change mitigation, rewetting farmed and drained peatlands is subject to debate, challenging the large number of intensive pasture-based dairy farms on drained peatlands in North-western Germany.

Shifts in societal values are perceived to translate into changing consumption patterns, i.e., a decreasing demand for meat and dairy products, coupled with an increasing demand for plant-based alternatives. Expectations for animal-, climate-, and biodiversity-friendly farming also rise, including consumers' demand for cattle to graze.

Biodiversity conservation is increasingly in the public's focus. Some interviewees noted a trade-off between biodiversity conservation and productivity, which is particularly challenging for intensive GBCF. For instance, maturing forage grasses positively affect biodiversity, but reduce forage quality.

Maintaining competitiveness and structural changes were additional challenges that interviewees mentioned. Challenges include unfavorable cost structures, volatile and increasing production costs, coupled with below-cost selling prices, and limited labor supply. In relation to this, a shift towards larger farms, with smaller farms exiting, was noted.

4.1.2 Influences of the identified landscape-level pressures on the established socio-technical regime

The identified landscape-level pressures challenge the established cattle farming regime by altering production conditions and market dynamics. Our interviewees stated that climate change complicates predicting vegetation growth and maintaining forage stability, with dry spells causing forage losses and high forage purchasing costs. Farmers must also adapt to longer growing seasons, increased pest and disease pressure, and grassland erosion from extreme weather.

While consumer demand for grazing rises, the experts noted that grazing is challenged by labor shortages, the need for larger pastures, climate change, and often a lack of shade. According to the experts, intensive, high-performance dairy farms may struggle to meet future forage needs from pasture alone, whereas confinement-based systems allow for easier supplementation. Extensive systems with robust breeds show more resilience to market volatility and changing forage quality. Consequently, some experts believe grazing may only survive where site conditions favor pastures or through subsidies, premiums, or direct marketing.

Shifting societal values are challenging farmers by affecting demand. Future concerns include the development of selling prices and how animal welfare is factored into milk and meat pricing. These changing consumer preferences also impact the marketing of grassland products. The interviewees noted that dairy cooperatives and certification bodies have introduced grazing premiums and biodiversity scoring systems. Additionally, one expert questioned how farms will comply with mandatory grazing under the EU organic label, especially when pasture forage is insufficient.

Historically, farmers integrated woody vegetation such as hedges into grasslands to prevent soil erosion and as fences. While hedgerows and orchard meadows provide important biodiversity benefits when properly maintained, their profitability is currently low. Many orchard meadows have also disappeared or become overgrown, aged, and diseased, requiring subsidies for maintenance and rejuvenation.

Concerning subsidies, one expert judged area-based payments as suited for incentivizing efficient food production, but as inefficient for society and food system resilience. A policy shift toward recognizing farmers as landscape managers was noted, however. An expert argued that biodiversity-friendly practices need fair compensation for production losses. However, farmers often view current payments as insufficient, fueling skepticism towards these practices. Some interviewees mentioned that farms also strategically use subsidies to optimize their operations, e.g., through extensification combined with conservation grazing.

4.1.3 Farm-level strategies for adapting to landscape-level pressure from climate change

In response to climate change, our interviewees identified several emerging farm-level adaptation strategies. The experts recommended building forage reserves, growing intermediate crops and more drought-tolerant forage species, and adjusting grazing management. Some mentioned diversification as a way to strengthen farm resilience.

Our experts cited the complexity of climate-smart measures as a key barrier to their adoption, illustrating a broader inertia among farmers. One interviewee highlighted this by pointing out that even simple, subsidized measures, such as installing additional drinking troughs for grazing animals, are often underused, despite the importance for heat-exposed animals. In contrast, some farmers have been forced into reactive, ex-post measures such as destocking during severe feed shortages, a practice one expert advised against due to the difficulty and time required to rebuild herds.

Our survey data shows that farmers engaging in ex-ante climate change adaptation reported having implemented four adaptation measures on average (Figure 2). Although most frequently reported, only 59% of all sampled farmers had increased their forage reserves, and 42% had provided additional water to their cattle on pasture. Farm income diversification was implemented by 22% of the surveyed farms, 19% had established additional woody vegetation on pastures to provide shade, 13% had increased other shelter opportunities, and 5% had increased both (see Figure 3).

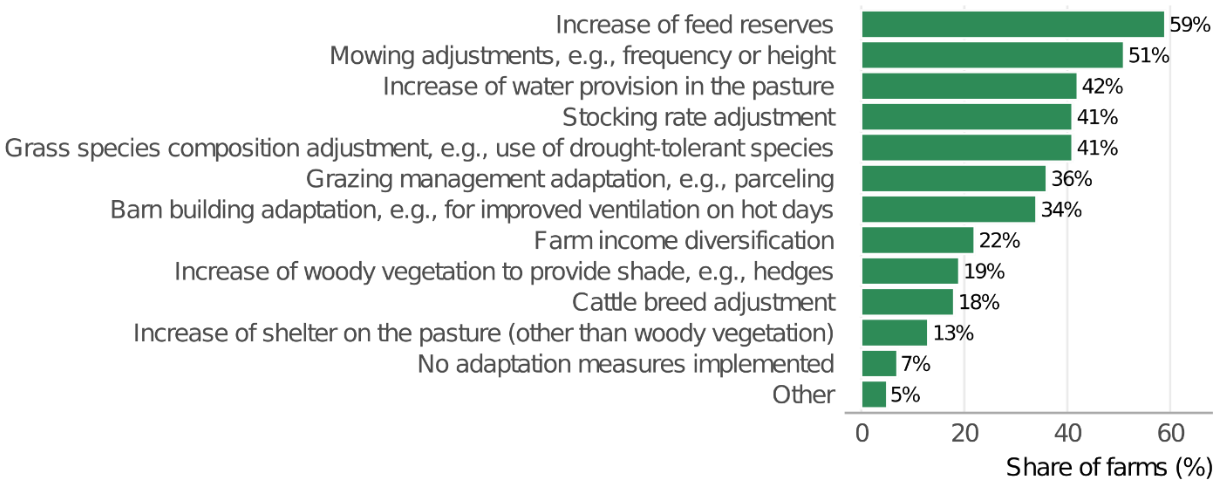

Figure 2: Survey respondents' (n=187) self-reported implementation of climate change adaptation measures.
Note: Multiple selections were possible, except if "no adaptation" was selected. While most of the adaptation measures are ex-ante, mowing adjustments can also be ex-post out of necessity during a dry spell.

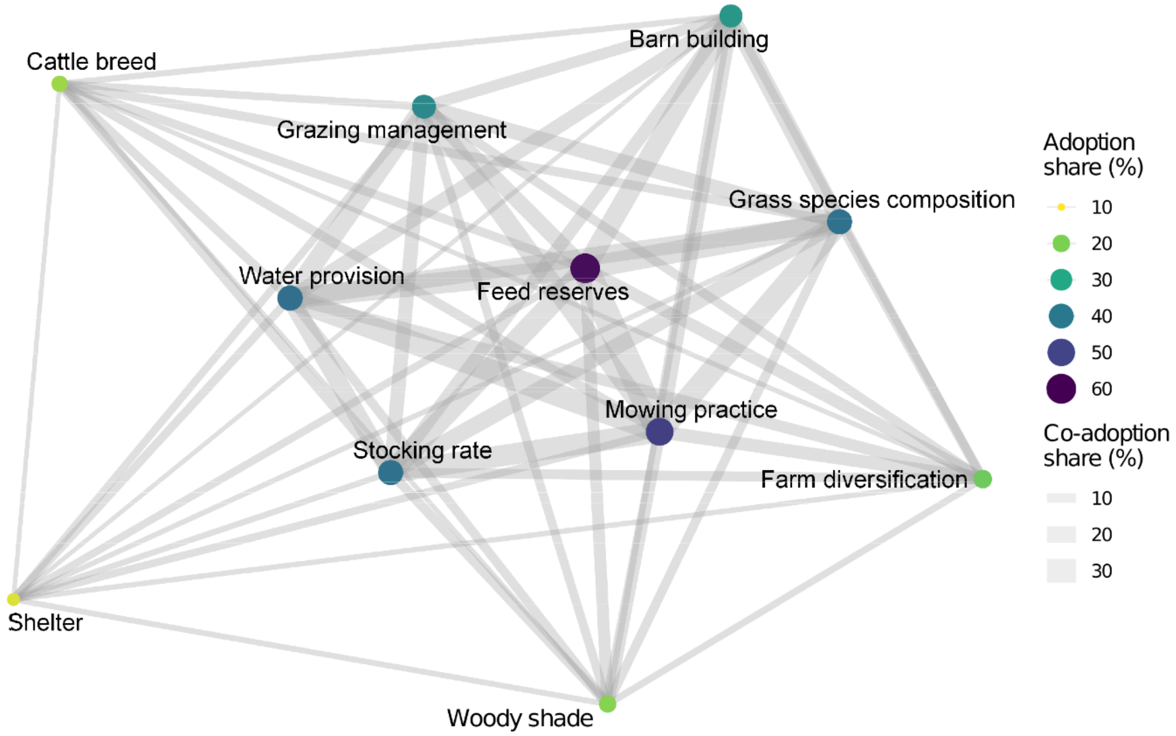

Figure 3: Network graph of farmers' reported adoption of climate change adaptation measures.
Note: The nodes (adoption percentage) denote the percentage of surveyed farmers implementing the practice. The weight of the grey lines between the nodes (co-adoption percentage) reflects the percentage of farms implementing both practices.

Experts also stressed the need to adjust grazing systems to cope with both drought and wet periods. However, the prevalent stand- or short-grass pasture system suits only sites with a steady water supply. Some experts reported that even intensive farms were reassessing pasture and grazing management. Our survey results support this view: 36% of the studied farms had changed their pasture management.

Experts mentioned night grazing, parceling (subdividing paddocks), and rotational grazing systems (including mob or holistic grazing) as potential adjustments.

> "And what is also increasing, of course, is that farms are also questioning their management practices. I've already mentioned mob grazing, where the number of inquiries has increased dramatically. (...) So you can hardly avoid the topic at any grassland event. I would say that five years ago this would have been unthinkable, because if you look at the forage material, (...) it would not have been an option, especially for more intensive farms." (I7)

Some interviewees viewed mob grazing as more feasible on beef farms, since it reduces milk yield per hectare. Yet, some dairy farms compensate for such lower yield through direct marketing. The experts also perceived a need for further research to optimize farmers' pasture management, and their species choice, to maintain yield quantity and quality. Some stressed that research struggles to deliver reliable results, preventing advisors from providing sound guidance on drought-tolerant species and alternative grazing management systems.

Notwithstanding experiences of cautious adoption of some adaptation practices, our expert interviewees highlighted that some farmers – due to increasing landscape-level pressures– progressively search for solutions and become more open to adopting innovations:

> "I almost have the impression that [farmers are] now so ready to embrace new things that you almost have to be a bit careful and make sure that official advice and official bodies and universities etc., can keep up with the research and deliver reliable results before these practices are actually implemented in the farm. So, it's not uncommon for me to hit the brakes and that's rather new for me. Usually, it has always been rather difficult, I would say, to initiate change. And there is definitely a different willingness now, because the pressure to solve the problem is different. If you reduce the animal stock and then half of the feeding places are empty, when you're standing in the barn, it simply does something to people. That is certainly a higher psychological burden." (I7)

4.2 Perceived opportunities, risk, and challenges associated with silvopastoral systems as a niche-innovation

According to our interviewees, modern agroforestry systems have attracted growing interest from policy, media, and farmers but remain a novel practice in Germany. Farmers already practicing agroforestry and silvopasture are viewed as 'pioneers.' They have formed associations and actively lobbied for improved regulations and subsidies to broaden adoption. In contrast, environmental and governmental organizations were perceived as more reserved, a view some interviewees shared. These differing attitudes likely stem from contrasting assessments of the opportunities, risks, and challenges of silvopastoral adoption within Germany's current policy and subsidy context, as discussed below and in detail in the annex (Tables A3 and A4).

4.2.1 Opportunities

Our interviewees mainly see opportunities from silvopastoral systems for pasture-based farms, as the benefits largely depend on *grazing animals*. Shade from trees lowers cattle's physiological stress, improving milk yields and growth. Leaf fodder serves as an alternative, high-value feed, benefiting cattle health. Some interviewees highlighted that visible animal comfort measures, such as shade and grazing provision, also constitute a consumer signaling opportunity and enable premium pricing of milk and meat products.

The interviewees highlighted that silvopastoral systems can improve grasslands' *micro-climate* by providing shade and acting as windbreaks, helping to reduce drought stress and stabilizing yields. Although grass growth under woody vegetation may be initially lower, faster regeneration in shaded areas can lead to more consistent production. The experts also mentioned possible positive effects on the structure, nutrient and water balance of soils, signaling potential for dry areas or marginal sites.

Silvopasture was also viewed as a means for *landscape and field structuration*, creating habitats and enhancing biodiversity. One policy expert emphasized that combining agroforestry with other structural landscape elements offers a promising opportunity to increase structuration in currently homogenous agricultural landscapes. Additionally, tree lines can parcel large plots for rotational grazing and guide cattle movement.

Farm diversification through silvopastoral systems was viewed as offering several opportunities for farms: First, producing energy wood and wood chips for heating, bedding, or fertilization (mainly on-farm); second, marketing fruits and nuts, especially via existing direct marketing; and third, creating long-term value for future generations with high-value timber. Fast-growing trees or short-rotation coppices were seen as easiest to integrate into a farm within the established socio-technical regime as they most closely resemble established agricultural practices. One expert recommended combining fast-growing trees with timber trees to benefit earlier from shade, windbreaks, and harvest from the former, and from long-term timber income from the latter. Lower branches of high-value timber trees are pruned for better timber quality, which, at the same time, improves machine access and provides broader, lighter shade than, e.g., hedgerows.

4.2.2 Risks

Key risks identified by the interviewees relate to the *higher complexity and labor demands* of silvopastoral systems, which farmers may underestimate. Establishing these systems requires careful planning, specialized knowledge and machinery, and significant labor resources to plant, protect, and potentially water trees in the planting year. Labor requirements for maintenance and harvesting are system dependent: fast-growing trees for biomass or energy wood require little maintenance but may require specialized harvesters; high-value timber trees require pruning and weed control for 15–20 years; fruit and nut trees need annual harvesting and marketing of mostly low quantities. Grazing animals complicate pesticide use and must be kept away at harvest time for hygiene. Unlike silvoarable systems, steady tree protection against animal damage (e.g., tripods or electric fences) is essential on silvopastures, at least in the initial establishment phase and when integrating high-value trees, raising investment costs.

Superficial *planning* and a lack of continuous monitoring and support are further perceived risks. As tree distances between rows are fixed, planners must anticipate future needs, such as desired stocking densities, machinery widths, and mature tree dimensions, to avoid creating obstacles. The intended end use of the trees (e.g., industrial timber, on-farm biomass, or energy wood) should also guide design decisions to ensure suitable wood quality. Farmers need support throughout the entire production cycle, because knowledge requirements change as trees mature. Conflicts with neighboring farms, regarding concerns about shade, reduced yields, or way maintenance, pose additional risks. Establishing agroforestry on leased land can be especially challenging, since lease terms are usually shorter than the lifespan of tree-based systems, requiring landowners' cooperation.

The *time horizon* of silvopastoral systems constitutes another key risk: Silvopastures require high upfront investments while marketable products and non-monetary benefits take years to materialize, making the land unavailable for other uses. Benefits, such as improved micro-climate and animal comfort, emerge only gradually. The time frame depends on the tree species. One expert noted that it is hard to quantify animal welfare gains from trees economically. Direct incomes from fruits or wood chips arise after several years; from high-value timber only after decades. Some interviewees therefore, consider fruit systems as interesting for farms with existing direct marketing channels. Others believe that fruit and nut production in silvopastoral systems will remain a niche, due to their low profitability compared to specialized plantations, small harvest volumes, and high labor demands.

Identified *grassland management risks* were linked to interactions between trees, cattle, and pasture. The interviewed animal system and grassland management experts highlighted risks associated with the uneven use of shaded and unshaded pasture areas by cattle. Overuse of shaded areas increases the risk of nutrient accumulation and of sward damage, especially under wet conditions, in those areas. Other interviewees attributed such overuse to poor system planning or insufficient shaded areas. Another concern raised was potential competition for water between trees and grasses. Tree selection was also emphasized as important, especially the avoidance of toxic species in grazing systems. Finally, leaf fall in autumn was mentioned as a factor that may reduce forage quality.

For *biodiversity*, silvopastoral systems are not always seen as unequivocally beneficial. For example, some experts cautioned against establishing them in areas where protected species depend on open land or where landscapes already feature substantial woody vegetation. The interviewees also mentioned stakeholder concerns that grassland extensification could benefit biodiversity more than adding trees without management changes, or that silvopasture may be a land-use change away from grassland.

4.2.3 Challenges arising from current framework conditions

Key challenges that the expert interviews unveiled include a lack of data and knowledge, farmers' negative past experiences with woody vegetation in agricultural landscapes, and apprehension towards the new agroforestry policy and associated subsidy schemes.

According to our interviewees, there is a *lack of arboricultural and agroforestry knowledge*. This is linked to trees having largely disappeared from farms and their management from agricultural training curricula. Official agricultural advisory services lack expertise on and long-term experience with agroforestry. The absence of certifications for planners also complicates support by official advisory services. Limited research data, for instance, regarding the effects of trees on forage quality, grassland yields under shading, fodder hedge productivity, water competition, and nutrient dynamics, such as phosphorus cycling, was also bemoaned. One grassland expert emphasized that many of these effects, such as tree density and shade levels, vary by system design, making it hard to generalize or give concrete advice with the current state of knowledge.

Negative *past experiences shape farmers' attitudes*, limiting their willingness to adopt agroforestry. This is partly due to misconceptions and poor system design, e.g., overuse of shade areas underneath single trees in pastures, poor spacing between trees for machinery usage, and beliefs regarding shade effects on grass growth. The experts also pointed out that some farmers remain skeptical about planting trees on valuable agricultural land, and that planting energy wood or timber on agricultural land – rather than food and forages – is a "paradigm shift" (I9) for most farmers.

Distrust in the new agroforestry scheme and biotope protection was highlighted as a key challenge by many experts. In the past, tree rows often had to be excluded from agricultural land. Farmers also feared that woody vegetation could be classified as landscape elements, making its removal difficult, limiting flexibility, and making maintenance burdensome. The German CAP 2023–2027 reform introduced two key simplifications: (1) trees in agroforestry systems can now lawfully be harvested and removed, and (2) the entire system remains classified as agricultural area, allowing farmers to claim the basic premium for the whole plot, including tree rows. However, expert interviewees noted that many farmers were still unaware of these changes, particularly that tree removal is permitted under the new scheme. More broadly, farmers' limited trust in the stability of the regulatory framework and concerns about future restrictions on tree removal were considered significant barriers. One expert shared how he, at times, argues with farmers, trying to convince them that current policies are taking a new direction:

> “I argue that we have seen that too much protection has led to a lot of orchard meadow trees being felled a few years ago, before they were placed under protection, and that this is also leading to a new course being tried now. Nevertheless, there is still a great concern that the trees cannot be removed regardless.” (I2)

Some interviewees remained cautious, also fearing that the removal, especially of long-lived timber trees, could be restricted later. For instance, if they are not well-maintained, thus losing their economic purpose and taking the character of biotopes, or due to policy changes.

The experts criticized the current *subsidy scheme as unattractive and inappropriate* due to inadequate maintenance payments and limited investment support. Bavaria was the only state to introduce an agroforestry investment subsidy already in 2023, yet uptake has been very low. Although the program covers up to 65% of costs, strict eligibility rules and a €2,500 minimum funding threshold favor larger systems. Bavaria has predominantly small farm structures, however. As a result, only seven applications were approved in the first year. One expert noted that while such schemes often require time to gain traction, a significant increase in applications is needed to justify their continuation and administrative efforts. More generally, the experts argued that the subsidy scheme should be restructured to target farmers with a strong willingness to adopt agroforestry, provide adequate investment and maintenance support, include advisory services, and differentiate payments to reward systems that generate greater public benefits.

4.3 Motivations for adopting silvopasture as a niche-innovation

4.3.1 Expert perceptions of farmers’ motivational factors for silvopasture adoption

The interviewees broadly agreed that adopting agroforestry under the new agroforestry scheme depends on a combination of two main factors: the system must be perceived as economically viable, and farmers must have intrinsic motivation, such as normative animal welfare concerns, innovativeness, or long-term value creation for future generations. External shocks, including drought, wind or water erosion, can also act as triggers for adoption. Subsidies, particularly investment subsidies, were seen as important to increase adoption. However, the current levels were perceived as insufficient:

> "The farmers who have implemented it or are seriously interested in it are already people who are a bit more independent from the opinion of the village about their own management. (...) I know several farms that have installed agroforestry systems without subsidies. And I would say that it is a strong conviction for a certain tree species or for certain systems that the farms are willing to implement such systems without subsidies.” (I8)

Together, these economic and intrinsic factors align with four key motives that the interviewees associated with silvopasture adoption: enhancing animal comfort and health, preserving grasslands, enhancing economic resilience, and promoting nature and biodiversity conservation.

Enhanced animal comfort through trees, especially shade provision, was seen as the most crucial motivating factor. Yet, interviewees' perspectives varied: Some experts argued that normative motivation is the strongest driver, while others believed productivity gains, or a combination of both, are decisive for adopting animal comfort measures.

Increased heat and drought phases can not only motivate farmers to plant trees to provide shade for animals, but also to *preserve grassland* and stabilize forage growth. Some interviewees noted improved regeneration in shaded areas in recent years:

> "Every farmer could see that where there was shade, there was more growth, and it's definitely an incentive to not lose any undergrowth with shade." (I6)

Enhanced *economic resilience*, as in farm income diversification and the protection and maintenance of existing farm activities, e.g., cattle grazing, was another highlighted motivation, especially where farmers feel "economically and emotionally" (I2) attached to these activities. In contrast, silvopastoral systems are less commonly implemented on highly intensive farms, according to the interviewees.

Nature and biodiversity conservation were also cited as motivating factors, for example, the creation of habitats or landscape diversity enhancements. Yet, as one expert put it, animal comfort is often "emotionally" (I4) more tangible than biodiversity or climate change, and therefore a stronger incentive. Furthermore, the interviewees suggested that biodiversity conservation tends to motivate the continuation or adoption of traditional agroforestry systems more than modern systems. Under the new agroforestry scheme, systems must serve an economic purpose, whereas traditional systems are often maintained for nature conservation or cultural reasons. For instance, one expert described orchard meadows as no longer economically relevant, as few contemporary farms are economically successful with orchard meadow products. They are mostly kept for nature conservation as a "hobby" (I4) or out of an "inner conviction" (I9). Regarding forest grazing, one expert explained that such systems often continue as a traditional land-use practice.

4.3.2 Valuation and planting of woody vegetation on pastures

23% of our survey participants reported that they had planted woody vegetation on cattle pastures in the past five years, i.e., after the 2018 drought in Germany (Figure 4). Orchard meadows were most often established, followed by single trees or bushes, hedgerows, and woodlots. Tree alleys for economic wood or timber production were least common. However, the new agroforestry scheme had only been in place for one year at the time of the survey. Notably, among farmers planting trees, a majority planted one type (60%), while 40% planted multiple types of woody vegetation.

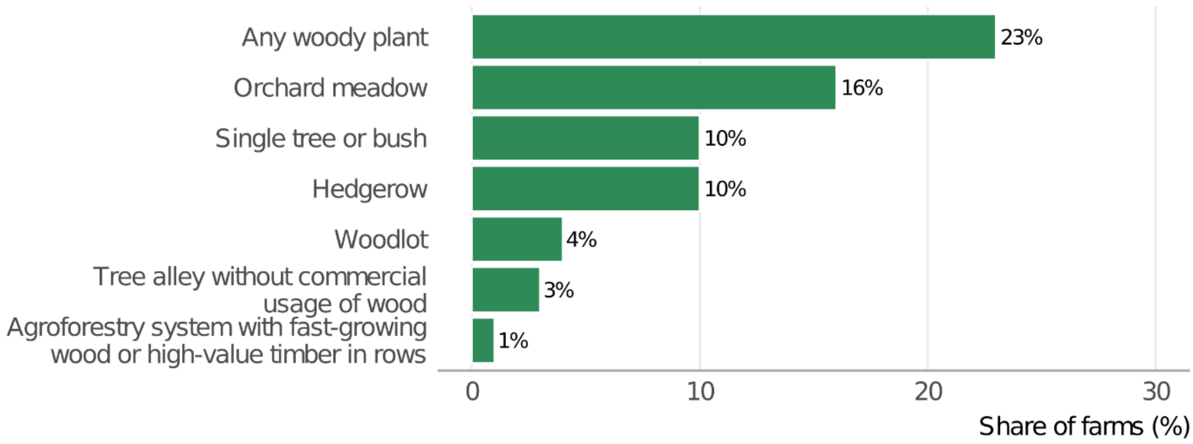

Figure 4: Type of woody vegetation planted by the survey respondents in past five years.
Note: based on 187 observations. Multiple selections were possible.

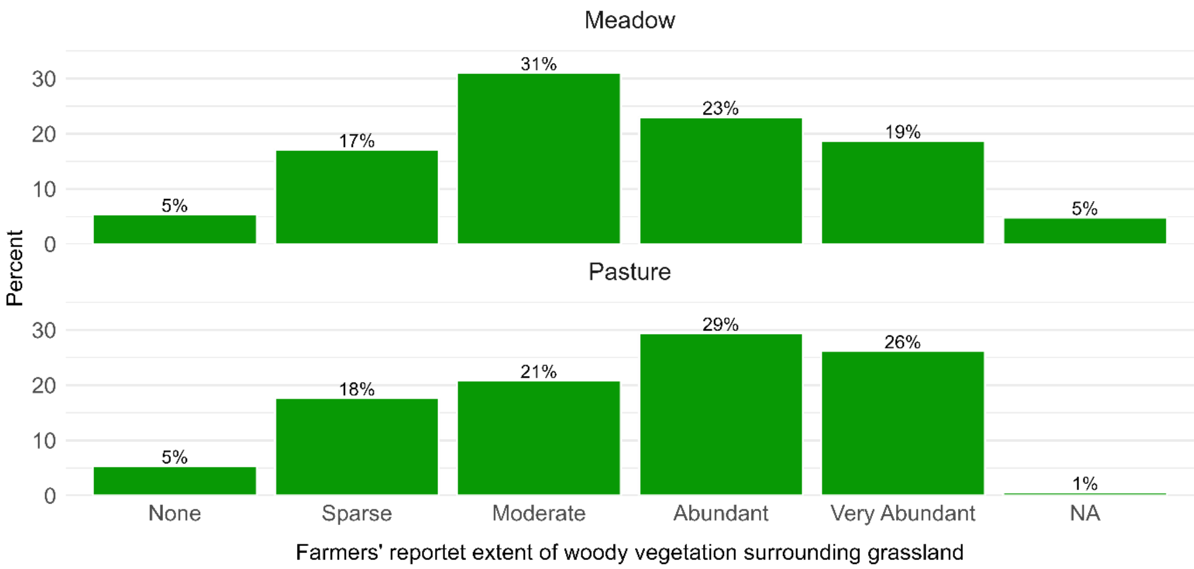

Figure 5: Reported extent of average woody vegetation surrounding meadows and pastures
Note: 'Sparse' means that the farm's grassland areas are sporadically surrounded by shrubs and hedges. 'Very abundant' means that at least half of the farm's grassland areas are surrounded on all sides by hedges or forest edges. A paired t-test suggests a difference in means between the extent surrounding pastures and meadows ($p < 0.01$).

The interviewed experts considered animal-related factors, such as welfare, health, or productivity, to be key motivations for silvopastoral adoption, and they observed particular interest among both dairy and non-dairy cattle-grazing farms. Our survey results support this as most farmers report higher extents of wood vegetation surrounding pastures than meadows (Figure 5) as well as shade and wind protection for cattle as the main preference for integrating woody vegetation into pastures (Table 4, Table A5). Indeed, 80% of the farmers ranked shade and wind protection among their top five purposes, with an average rank of 1.9 in Table 4 and an odds-ratio of 23.68 in Table A5. Biodiversity conservation was the second preference (40% of farmers and average rank of 3.2 in Table 4, odds-ratio of 6.14 in Table A5). Most preferred marketable products from woody vegetation were fruits, wood chips, timber, and energy wood. More farmers prioritized high-value meat products (28%) over high-value milk products (16%). Yet those farmers who selected milk products, i.e., dairy farmers, ranked them higher (1.6 vs. 2.2 in Table 4 and model (2) of Table A5).

Table 2: Farmers reported main purposes for the inclusion of woody vegetation into pastures

Purpose	**Percentage of farms (%)**	**Average rank**	**Associated ecosystem services**
Shade and wind protection for cattle	80	1.9	regulating, provisioning
Biodiversity conservation	40	3.2	supporting
High-value meat products	28	2.2	provisioning
Fruit	31	2.8	provisioning
Biomass for wood chip production	24	2.1	provisioning
Improving/Balancing of micro-climate	29	3.0	regulating
(High-value) timber	26	2.8	provisioning
Energy wood	22	2.4	provisioning
High-value milk products	16	1.6	provisioning
Improvement of water balance	20	3.4	regulating
Carbon storage	17	3.7	regulating
Aesthetic enhancement of field plots	12	3.4	cultural
Nuts	10	3.4	provisioning
Higher land productivity	8	3.6	supporting, provisioning
Economic enhancement of field plots	8	3.6	provisioning
Honey	5	3.0	provisioning
Improvement of nutrient balance	3	3.7	supporting
Berries	3	3.2	provisioning
Leave fodder	3	3.8	provisioning
N	172		

Note: Out of 19 possible purposes, farmers could choose and rank up to five purposes from most important (rank 1) to least important (rank 5), why they would (hypothetically) include woody vegetation in pastures. Associated ecosystem services were not provided in the questionnaire.

5 Discussion

In this study, we applied the Multi-Level Perspective (MLP) framework to explore opportunities, risks, and challenges as well as farmer motivations and contextual factors shaping silvopasture uptake in Germany. Our findings show that GBCF with grazing cattle face multiple pressures – from climate change and structural change to societal demands for biodiversity and animal welfare.

5.1 Niche dynamics, landscape pressures, and the multi-level transformation process

We identify evidence of a multi-level transformation process in Germany's GBCF sector: niche-innovations, such as agroforestry, gain internal momentum, while socio-technical landscape pressures and gradual regime destabilization create windows of opportunity for the diffusion of niche-innovations (Geels 2019). We find signs that agroforestry, especially the adoption of silvopastoral systems, is mainly in the experimentation phase, characterized by pioneering actors, high uncertainty, and learning by doing (Geels 2019, Kemp et al. 1998). Yet, there are signs of early diffusion, including the formation of farmer networks, policy advocacy efforts, and increasing political recognition. This suggests that niche-level activities are starting to influence broader regime dynamics in Germany. Similar dynamics are observed in parallel in other European countries, such as Slovakia (Mitrová et al. 2025).

Our results show that multiple socio-technical landscape trends increase pressure on the dominant regime, prompting a search for solutions. While some experts noted that farmers used to be cautious about adopting innovations, rising pressures now motivate some to act despite remaining uncertainties regarding farm-level outcomes. In line with Sutherland et al. (2012), we found indications that shocks, such as extreme weather events, can trigger agroforestry adoption. Consistent with the MLP framework, this fosters parallel (sub-)regime developments and multiple niche-innovations (Geels 2019), including silvopasture and mob grazing, as farmers experiment with alternative practices to increase resilience and adapt to changing conditions. This dynamic is mirrored in Australia, where Holistic Grazing Management has emerged as a niche grazing practice, often adopted in response to crisis or by a younger, more educated generation (Messner et al. 2025).

Creating a protective niche for agroforestry through pioneers, policymakers, and associations helps reduce uncertainty and foster learning. Our interviews show that farmer networks advocate for policy change, as agroforestry gains attention in media and politics, suggesting a growing momentum. The experts in our study judged current agroforestry-related subsidies as insufficient to motivate more widespread adoption, i.e., perceived too little protection by policy-makers. Since the interviews, policy-makers have engaged in niche management by adjusting the eco-scheme subsidy in the course of the CAP 2023-2027, i.e., by simplifying regulations and through a stated objective of increasing the premium (Ministerium für Ernährung, Ländlichen Raum und Verbraucherschutz 2025, BMEL 2024b). In addition to these adjustments, our results suggest that providing investment support linked to positive externalities and ensuring access to qualified advisory services could improve the scheme.

In their study, Messner et al. (2025) conclude that innovative grazing practices may be absorbed rather than triggering a full regime transformation in Australia as the niche remains fundamentally reliant on the dominant regime for key functions, while there is no policy support. This offers a compelling point of comparison for the German context, though for different underlying reasons. In Germany, the dominant grassland-based cattle-farming regime comprises both grazing and non-grazing systems. Our findings indicate that the potential for integrating trees is higher on pastures than on meadows. However, grazing farms are in decline, among other reasons, due to structural change and labor shortages. This creates a central challenge: silvopasture, as an innovation, is most beneficial for those farms that are currently in decline. Therefore, while silvopasture may be a key adaptation strategy for grazing farms, notably also organic farms with grazing requirements, its potential to transform the entire regime remains limited, as long as its primary potential pertains to the contracting part of the regime.

5.2 Lock-ins and challenges hinder the adoption of silvopastoral systems

Our results indicate that silvopasture adoption is challenging for farmers due to multiple lock-ins in the current regime, substantiating previous findings (Louah et al. 2017, Klimke et al. 2025). Specifically, we find institutional lock-ins that arise from subsidy structures focused on efficient food production, despite perceived gradual policy shifts toward results-based payments, and a shifting view of farmers as landscape stewards. Social lock-ins are evident from our finding that agroforestry adopters tend to be more independent of peer opinion. Finally, cognitive lock-ins are reflected in farmers' skepticism about planting trees on valuable land, and an expert's remark that adopting agroforestry is often a paradigm shift for farmers.

The long and uncertain return on investment of agroforestry, and silvopastoral systems in particular, has raised doubt about their profitability within the dominant regime (Frey et al. 2013, Thiesmeier and Zander 2023, Geels 2019). Nonetheless, our findings suggest that farmers' silvopasture adoption decisions are not purely driven by economic reasoning. Our interviewees highlighted farmers' intrinsic motivations, mindset, innovativeness, and their conviction in the system's value as important. Our quantitative results substantiate the view that animal comfort is a key motivation for integrating woody vegetation into pastures. A recent study in Slovakia also underlines the importance of intrinsic motivations for agroforestry adoption (Mitrová et al. 2025). Rip and Kemp (1998) and Geels (2019) further argue that regime 'insiders' – in our case more intensive conventional farmers, who are under high market pressure – may have less scope to experiment and take risks and are more locked into the dominant regime than 'outsiders'. Finally, our interviewees perceived early adopters as innovative, in line with findings from Kaine et al. (2023).

Our findings show that integrating trees on pastures for shade can be an adaptation strategy for grazing farms. However, alone it is insufficient to address broader climate change challenges, thus, should be accompanied by other measures. The opportunities, risks, and challenges of silvopastoral systems that experts in our study identified complement results of previous studies, e.g., by Rolo et al. (2020) and Smith et al. (2012), in more detail and for the specific case of modern silvopasture in Germany. Key opportunities that our research identified relate to grazing and pasture management (e.g., animal comfort, micro-climate benefits), value generation, and biodiversity. Our survey results support experts' views that the potential of silvopasture is higher for grazing farms. Building on the latter, perceived disadvantages emerging from our study include system complexity, higher labor needs, long and uncertain returns (compare Long et al. 2016), challenges in grazing management, such as nutrient imbalances, and effects on biodiversity. The agroforestry experts in our study generally perceived lower risks, arguing these can be mitigated through tailored system design. In contrast, experts from other fields more often raised concerns, such as machine requirements, nutrient imbalances, and competition. One explanation for these contrasting perspectives may be experts' dissimilar experiences, exposure to farmer groups, and areas of research.

5.3 Enabling adoption through policy, knowledge, and participation

Our results suggest that successful implementation of silvopasture requires integration into existing farm operations. Underpinning Reeg (2011), we find that these systems must fit farmers' resources, knowledge, and goals. Combining fast-growing and high-value trees may optimize benefits and returns, and starting with simpler systems can ease the learning curve for farmers. Our results substantiate arguments by Louah et al. (2017) and Reeg (2011) that arboricultural knowledge is largely lost among farmers and agricultural advisors. These knowledge deficits are problematic, as better upfront planning could help prevent silvopasture-related challenges that our research identified – including shade-related nutrient imbalances and the creation of obstacles for machines. As suggested by the qualitative findings, policymakers may therefore want to invest in accredited advisory services to support farmers willing to adopt silvopastoral systems throughout the entire implementation cycle.

We found that German agroforestry experts perceive a strong distrust among farmers regarding the stability of current agroforestry-related policies, as well as skepticism towards biodiversity regulations, which are seen as limiting flexibility or profitability. Requirements to maintain hedges, for example, are viewed as burdensome, and biodiversity-enhancing measures as inadequately compensating productivity losses. These findings indicate that future agroforestry policy frameworks must credibly ensure that farmers retain the flexibility to remove agroforestry elements from their land, and that these elements serve an economic purpose until harvest, for example through contract design (Brouwer et al. 2015, Schulze et al. 2024). Highlighting productive uses of trees or hedges may reduce perceived burdens and increase acceptance.

We found that the multiple pressures that GBCF face from the landscape levels create a window of opportunity for agroforestry innovations to be adopted, even under uncertainty. Policymakers and advisors should be cautious about scaling silvopastoral systems too quickly, however. Given the existing skepticism that our study highlights and the missing research data for informed advisory that the experts criticized, there is a risk of rejection of ill-adapted systems to farm-specific contexts (compare Elzen et al. 2011). To mitigate this risk, policymakers could support the co-creation of context-specific solutions through strategic niche management (Geels 2019, Kemp et al. 1998), involving farmers directly in agroforestry research and design processes. Participatory research and networks such as the European Innovation Partnership 'Agricultural Productivity and Sustainability' (EIP-AGRI) and agroforestry associations are crucial for tailoring systems to farm contexts, fostering knowledge exchange, and identifying leverage points for change (Richardson et al. 2022, Schreuder et al. 2022).

6 Conclusion

As climate-related risks, the biodiversity crises, and shifting consumer demands heighten pressure on GBCF, innovative practices that fit farmers' needs and changing production circumstances need to be found and adopted. Our study advances this process by appraising silvopastoral systems as a niche-innovation with the potential to transform the established cattle-farming regime and enhance the resilience of GBCF in Germany. Our application of the Multi-Level Perspective illustrates how landscape-level pressures challenge the established farming regime, thereby shaping farmers' decisions to adopt niche-innovations, including silvopasture.

Key learning points from our study are that: i) increasing socio-technical landscape pressures, especially climate shocks and societal demands, are actively destabilizing the conventional cattle-farming regime. This creates crucial "windows of opportunity" for niche-innovations such as silvopasture to gain momentum as farmers are prompted to search for more resilient and sustainable practices. ii) The decision to adopt silvopasture is a trade-off between opportunities, in particular enhanced animal welfare in grazing systems, and risks and challenges, including institutional and cognitive lock-ins. Crucially, farmers' adoption decisions are driven by a combination of economic and intrinsic motivations. iii) Broader silvopasture adoption would require further policy support. This includes building a stable and trustworthy policy framework, developing expert advisory services to overcome critical knowledge gaps, and using participatory approaches to develop context-specific solutions that farmers can realistically implement.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used Llama (Meta) standalone to assist in translations and ChatGPT (OpenAI) to assist in language revision, and to improve the grammar and readability of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the article.

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8 Annex

Table A1: List of interviewed experts

Number	Expertise
I1	Agroforestry
I2	Agroforestry
I3	Animal systems
I4	Agroforestry
I5	Grassland management
I6	Animal systems
I7	Grassland management
I8	Agroforestry
I9	Agri-environmental policy
I10	Forest grazing

Table A2: Interview guide

Original version: German	**Translated version: English**
Herausforderungen und Risiken von Betrieben mit Grünland 1. Mit welchen Herausforderungen und Risiken sind Betriebe mit Dauergrünland in Zukunft konfrontiert? a. Gehen Sie hier insbesondere auf (1) Markt und Preise, (2) Regulierung und Gesetzgebung, und (3) Produktion, Biodiversität und Klimawandel ein. b. Gehen Sie auf Milchvieh- und Rindermasthaltung, jeweils in Weide- und reiner Stallhaltung ein. Gehen Sie eventuell auch auf Schaf- oder Ziegenhaltung ein. 2. Welche Herausforderungen stellen sich speziell für das Grünlandmanagement? 3. Welche Anpassungen nehmen Betriebe vor, um die Risiken und Herausforderungen zu reduzieren?	**Challenges and risks for farms with grassland** 1. What challenges and risks will farms with permanent grassland face in the future? a. In particular, please address (1) market and prices, (2) regulation and legislation, and (3) production, biodiversity and climate change. b. Describe dairy cattle and beef cattle husbandry, both in pasture and confinement-based systems. You may also discuss sheep or goat husbandry. 2. What are the specific challenges for grassland management? 3. What adjustments are farms making to reduce the risks and challenges?
Chancen und Risiken von silvopastoralen Systemen Ein silvopastorales System ist ein Landnutzungssystem, in dem Gehölze (Bäume und Sträucher) mit Tierhaltug auf einer Fläche kombiniert werden, um von ökologischen und ökonomischen Wechselwirkungen zu profitieren. Im nachfolgenden interessieren wir uns für silvopastorale Systeme für die Nahrungsmittel-, Futter-, und Wertholzproduktion, jedoch nicht für Energieholzstreifen im Kurzumtrieb. Das heißt im	**Opportunities and risks of silvopastoral systems** A silvopastoral system is a land-use system in which woody plants (trees and shrubs) are combined with livestock farming on the same area in order to benefit from ecological and economic interactions. In the following, we are interested in silvopastoral systems for food, fodder and timber production, but not as short rotation coppice systems for energy wood. This means in particular fruit or nut

Original version: German	**Translated version: English**
Speziellen Obst- oder Nussbäume und -sträucher, Werthölzer und Futterhecken auf Grünland. 4. Welche Chancen bieten silvopastorale Systeme mit Bezug auf die zukünftigen Herausforderungen? 5. Welche Risiken sind mit silvopastoralen Systemen verbunden?	trees and shrubs, high-value timber and fodder hedges on grassland. 4. What opportunities do silvopastoral systems offer with regard to future challenges? 5. What risks are associated with silvopastoral systems?
Rahmenbedingungen 6. Welche Rahmenbedingungen halten Landwirte davon ab silvopastorale Systeme einzuführen? 7. Die Rahmenbedingungen für Agroforst und speziell auf Grünland haben sich ab 2023 verändert. Inwiefern hat sich das auf das Potential und die Hindernisse der Einführung eines silvopastoralen Systems ausgewirkt?	**Framework conditions** 6. Which framework conditions prevent farmers from introducing silvopastoral systems? 7. The framework conditions for agroforestry and especially on grassland have changed since 2023. To what extent has this affected the potential and obstacles to introducing a silvopastoral system?
Ausgestaltung von silvopastoralen Systemen 8. Welche silvopastoralen Systeme könnten für welche Betriebe interessant sein? a. Gehen Sie auf Betriebe mit Milchvieh- und Rindermasthaltung mit und ohne Weidehaltung ein. Gehen Sie eventuell auch auf Schaf- und Ziegenhaltung ein. b. Gehen Sie auf Betriebe, die ihre Herde vergrößern oder verkleinern wollen, ein. 9. Welche Entscheidungsfaktoren berücksichtigen Landwirte, wenn sie ein silvopastorales System einführen wollen?	**Design of silvopastoral systems** 8. Which silvopastoral systems could be interesting for which farms? a. Describe farms with dairy cattle and cattle husbandry with and without grazing. You may also consider sheep and goat husbandry. b. Describe farms that want to increase or reduce the size of their herd. What decision factors do farmers take into account when they want to introduce a silvopastoral system?

Table A3: Advantages and opportunities of silvopastoral systems

Topic	Issue	Advantage	Opportunities
Grazing and pasture management	**Animal comfort and health**	• Trees provide **shade, wind, and weather protection**, improving animal comfort and health. • Cattle have cooler comfort temperatures and less physiological stress at lower temperatures, leading to better **milk and growth performance**. Trees can create a more comfortable climate for animals on the pasture through cooling and shading, but AFS do not replace the barn in the summer at very high temperatures. • **Timber** trees with the lower branches cut are interesting for grazing due to the **large radius of light shade**. Wild cherry already creates shade after about ten years. • Tree lines are usually planted in north-south direction if acting as wind barriers and to decrease maximum shade. For animal comfort, tree lines may be planned in east-west direction to increase shade in particular during warmest periods of the day. • Grazing can reduce pest pressure from mice in grasslands and tree alleys. • **Leave fodder** and fodder hedges can serve as additional feed, with high feed value, comparable to grass, and containing secondary plant compounds beneficial for animal health.	• **Opportunity to strengthen farm branch** for farms wanting to maintain their main activities. • **Opportunity for grazing farms**, especially dairy farms with grazing or free-range chicken. Less benefit for farms with only meadows. • **Opportunity for small farms** with less regulations on management and smaller machines. However, minimum requirements on distances make AFS less suitable for small plots. Experts are mostly undecided whether there is more opportunity with small, medium or large farms. • **Opportunity for parceling and structuration of large plots** for rotational grazing. • **Opportunity for dry area** due to the micro-climate effects and water-holding capacity of the trees. • Keyline systems are designed to conserve water on the land by following the contours of the terrain and using ditches and ponds to retain water and prevent erosion. However, they can be complex and require a high level of planning and maintenance, and are considered a niche topic by some experts due to their limited understanding and potential drawbacks.
	Pasture micro-climate	• Trees can improve the micro-climate through shade and their function as wind barriers mitigating extreme weather conditions. • Shade from trees increases evapotranspiration and as wind barriers they prevent wind from moving wet air and drying out land. This can reduce drought stress for grasses and lead to more stable grass yields.	

Topic	Issue	Advantage	Opportunities
		• Grassland regeneration is faster in the shade, with less yield at the first cut, but more at the second and third.	
	Soil improvement	• Trees can reduce **nutrient leaching** into the groundwater. • Trees can **extract nutrients** such as phosphorus from deeper soil layers. Biomass from trees can be applied to arable land to improve humus buildup. • Trees can improve soil fauna compared with intensively used grassland by changing and **improve soil structure**. • Trees can **retain water** in the soil through their roots, and certain trees such as willows were traditionally planted to extract moisture from the soil.	
	Increased land productivity and optimization of land use	• The addition of timber or fruit trees can increase land productivity and economically upgrade grassland without limiting its ecological functions and loosing too much grass growth. • Hedges and tree rows can structure and partition pastures for optimized land use. Livestock can be moved along the structures in and out of the pastures.	
Value generation and profitability	**High-quality products and income diversification**	• High-value animal products, such as dairy products can be achieved through improved performance in dairy cattle or through marketing of animal welfare/comfort products. • Stabilizing farm income through diversification of income sources from timber, energy wood, fruit and nut trees such as walnuts and chestnuts.	• **Combining fast-growing trees** (e.g. poplar, willow) generates quicker benefits through shade and provides economic benefits (energy wood, wood chips) in medium-term **with high-value timber trees** for long-term benefits • **Opportunity for farm diversification**, in particular with fruit. KUP strips are interesting for wood chip production and as bedding material. • **Opportunity for direct marketing or regional marketing** in a consortium of several farms with a
	New regulation for agroforestry	• Unlike landscape elements, trees can be removed in the agroforestry land-use scheme which offers more flexibility • No grassland conversion triggered for planting trees on grassland in agroforestry land-use scheme	

Topic	Issue	Advantage	Opportunities
		• Basic payment is paid for the entire agricultural plot including tree alleys	possible marketing label for products from agroforestry, such as fruits, walnuts, or high-quality milk and meat. • **Opportunity to generate value for future generations** with high-value trees • **Subsidies are available**, however, too low and not adapted to needs limiting adoption.
Biodiversity	**Biodiversity and landscape**	• Some experts see general benefits for biodiversity in AFS, while others only see benefits in intensively used grassland. • The structural diversity of AFS can relax the agricultural landscape.	• **Opportunity for regions with lower structuration of agricultural land**. Less benefit for areas and farms with high shade, such as in regions with high structuration or farms with many hedges or near forest edges. • **Opportunity for increasing biodiversity in intensive grasslands**

Table A4: Drawbacks and risks of silvopastoral systems

Topic	Issue	Drawback	Risks
Complexity and labor requirements	**Complexity of agroforestry systems**	• Silvopastoral systems are higher in complexity than grassland systems. • Establishing agroforestry systems requires a significant planning effort. • Knowledge and technology must be acquired. • The distance between tree rows is fixed, limiting the width of machines and future machine purchases. Larger farms relying on large machines may find trees more of a hindrance.	• **Poor planning** leads to more labor effort in management or requires special machines that were not accounted for. Inadequate or superficial planning can create obstacles, making management problematic. Planning must consider future generations and the mature width of trees to avoid creating future obstacles and reducing travel times.

Topic	Issue	Drawback	Risks
		• The more competitive the crop (e.g. intensive grassland species), the more difficult it is to establish the planting material successfully.	• **Insufficient support** from planners in later years as knowledge is required at different stages of maturity of systems • **Underestimating labor effort**, especially in the first years • **Difficulty in establishing plant material**, especially in highly competitive grassland or arable land • **Tree damage** through grazing animals. • **Starting with too complex a system**, which overloads labor effort and management • **Unavailability of planned plant material** at the time of planting • **Unavailability of special machines** • **Biotope protection** might still apply even if it was declared as agroforestry if timber rows are not maintained, dead wood is not removed, and economic use is thus no longer a main objective.
	Additional labor requirements	• Trees require an additional labor effort. Additional work steps must be integrated into the work process: watering in dry establishment years, establishment and tree protection (fencing), maintenance (weed control, pruning, mowing between timber trees to reduce pest pressure), and harvesting must be organized and are essential for the trees to grow well. • High-value timber trees are require some effort at the planting stage and need some further maintenance in the following years, however, are less labor intensive than fruit trees. • Stable tree protection is necessary for grazing, which requires a high labor effort. The effort and cost to fence and protect individual trees, such as in orchard meadows, are even higher.	
	Combining food production and livestock on the same land	• Combining food production and livestock on the same land is associated with a higher labor effort. The fruit must be harvested and not left on the ground to prevent future fruit diseases. • The harvest must be integrated into the ongoing operation at harvest time, and the marketing must be organized. If there is no storage, apple varieties must be chosen that can be harvested at the right time to be sold immediately. • Spoiled fruit must be removed to prevent an infection cycle and ensure good harvests in the future. This is a problem that contributed to problems of orchard meadows. • Grazing is not possible during fruit harvesting due to hygiene reasons and using pesticides is more difficult with grazing.	

Topic	Issue	Drawback	Risks
		• Temporary grazing of AFS with fruits by geese or chickens may be more suitable (mainly interviews with orchard meadow experience).	
Return on investment	**Time period for benefits to realize**	• Non-monetary benefits of agroforestry are not immediate, but rather medium-term, through micro-climate improvement, shading for improved animal comfort, etc. • Fast-growing trees and shrubs can be planted to generate shade more quickly, but also wild cherry trees provide benefits through shade after about ten years. • Monetary benefits from harvesting timber or fruits occur in the long-term respective medium-term.	• **Uncertainty of continuation of Germany's agroforestry maintenance subsidies** which is only secured for five years, after which continuation is uncertain while it takes several years for trees to establish and provide benefits. • **Risk of tree loss**, due to tree mortality, windfall or beetle infestation. This is more important for long-standing high-value trees. • **Policy changes** are more likely due to the long lifespan of high-value trees. Different circumstances in the future could for example lead to the protection of trees in agroforestry systems for nature conservation • **Leased land** agreements can be terminated before harvest. • **Unplanned costs**, e.g. through initial watering in a dry establishment year or planning errors. • **Uncertainty whether fodder hedges can be an agroforestry system in all German states**
	Long-term planning and maintenance	• The long lifespan of trees justifies an intensive planning phase to avoid errors. Planning must consider multiple generations, and the harvest often occurs in the next or subsequent generation. • Depending on the trees and systems, more or less maintenance is required until the harvest.	
	Leased land	• Establishing agroforestry on leased land is difficult due to the long-term nature of the system which often outdates land leases. • The landowner must be convinced of the system, but are often concerned that the land may lose its agricultural status or be classified as non-agricultural land.	
	High initial investment	• The initial investment volume is high and must be borne by the farm if no investment subsidies are available. • Systems with grazing are much more expensive due to tree protection against browsing of ruminants.	

Topic	Issue	Drawback	Risks
		• In many federal states, there is no investment subsidy. Smaller systems are excluded from the investment subsidy due to the minimum subsidy amount.	
	De facto loss of agricultural land	• Agricultural land is lost for alternative production, which weighs higher until benefits occur from trees.	
Grazing and pasture management	**Grassland conversion**	• Grassland conversion during tree establishment can lead to short-term carbon and nitrogen releases. Plowing must be limited to narrow planting strips.	• **Uneven nutrient input** in shade areas, particularly on large pastures without regular rotation. • **Soil compaction and sward damage** from shade overuse in the root zone of the trees. • **Water competition** between trees and grass.
	Overuse of shade areas	• In particular when shade areas are small and systems are not planned well, ruminants may overuse areas under trees due to shade preference, leading to nutrient imbalances and damage to the grass sward.	
	Leaf Fall	• Leaf fall in autumn can affect forage quality. Trees with toxic leaves must not be planted, even with adequate fencing, if the pasture is used during leaf fall.	
Biodiversity	**Biodiversity**	It may be sensible not to establish silvopastoral systems in certain areas, for example in areas where protected species such as great bustards (*Otis tarda*) and northern lapwings (*Vanellus vanellus*) rely on open land or in grasslands high in nature value or wet meadows.	• A positive **effect on biodiversity** may only be significant for very intensive grassland and depends on the diversity of the system.

Table A5: Odds-ratios based on a rank-ordered logit choice model of farmers' preferences as to why integrate woody vegetation into pastures

	All farmers (1) Farmer ranking		Dairy farmers (2) Farmer ranking	
Economic enhancement of field plots (base)	1.00	[1.00,1.00]	1.00	[1.00,1.00]
Higher land productivity	1.00	[0.46,2.15]	1.11	[0.45,2.72]
High-value meat products	**4.46**	[2.41,8.24]	**5.25**	[2.52,10.93]
High-value dairy products	**2.36**	[1.22,4.56]	**0.11**	[0.01,0.85]
Fruits	**4.73**	[2.58,8.67]	**4.20**	[2.01,8.80]
Nuts	1.40	[0.68,2.85]	1.58	[0.68,3.65]
Berries	0.38	[0.14,1.07]	0.33	[0.09,1.21]
Honey	0.61	[0.25,1.47]	0.44	[0.13,1.42]
(High-value) timber	**3.73**	[2.01,6.94]	**3.86**	[1.84,8.13]
Energy wood	**3.22**	[1.72,6.06]	**2.67**	[1.23,5.81]
Biomass for wood chip production	**3.67**	[1.97,6.84]	**2.84**	[1.31,6.14]
Leave fodder	0.46	[0.17,1.20]	0.43	[0.13,1.40]
Shade and wind protection for cattle	**23.68**	[13.30,42.16]	**20.95**	[10.37,42.30]
Biodiversity conservation	**6.14**	[3.39,11.13]	**5.12**	[2.47,10.60]
Carbon storage	**2.30**	[1.19,4.42]	1.81	[0.80,4.11]
Improving/Balancing of micro-climate	**4.50**	[2.44,8.29]	**3.64**	[1.71,7.72]
Improvement of water balance	**2.81**	[1.48,5.32]	2.09	[0.94,4.67]
Improvement of nutrient balance	0.45	[0.17,1.20]	0.43	[0.13,1.40]
Aesthetic enhancement of field plots	1.61	[0.80,3.21]	0.97	[0.39,2.46]
Dairy is <u>not</u> main farm activity (base)			1.00	[1.00,1.00]
Dairy is <u>not</u> main farm activity x Economic enhancement of field plots (base)			1.00	[1.00,1.00]
Dairy is main activity x Higher land productivity			0.68	[0.12,3.91]
Dairy is main activity x High-value meat products			0.63	[0.16,2.43]
Dairy is main activity x High-value dairy products			**85.39**	[8.40,868.05]
Dairy is main activity x Fruits			1.41	[0.38,5.16]
Dairy is main activity x Nuts			0.63	[0.13,3.19]
Dairy is main activity x Berries			1.54	[0.18,13.09]
Dairy is main activity x Honey			2.31	[0.37,14.25]
Dairy is main activity x (High-value) timber			0.91	[0.24,3.48]
Dairy is main activity x Energy wood			1.67	[0.44,6.41]
Dairy is main activity x Biomass for wood chip production			1.97	[0.52,7.43]
Dairy is main activity x Leave fodder			1.18	[0.15,9.32]

Dairy is main activity x Shade and wind protection for cattle		1.45	[0.42,5.00]
Dairy is main activity x Biodiversity conservation		1.64	[0.46,5.87]
Dairy is main activity x Carbon storage		1.87	[0.47,7.48]
Dairy is main activity x Improving/Balancing of micro-climate		1.76	[0.48,6.51]
Dairy is main activity x Improvement of water balance		2.11	[0.54,8.21]
Dairy is main activity x Improvement of nutrient balance		1.16	[0.15,9.17]
Dairy is main activity x Aesthetic enhancement of field plots		3.15	[0.73,13.59]
Observations	3268	3268	

Exponentiated coefficients; 95% confidence intervals in brackets; base category: Economic enhancement of field plots. 172 farmer observations and 19 potential options gives 3268 observations. Exponentiation transforms zero to one, thus, confidence intervals including one suggest that the purpose is not an important purpose for our sample.