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Agroforestry adoption in Germany: using decision analysis to highlight the effects of institutional barriers and funding options on system profitability

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Abstract

After introducing agroforestry (AF) for the first time into national funding legislation in 2023, Germany aimed to fund 25,000 ha of AF via the new annual funding scheme. Although several federal states have additionally introduced investment support measures for the establishment of AF systems, only 51 ha of AF were funded in 2023. The low demand for the subsidies indicates that their adequacy needs to be questioned. Additionally, institutional barriers to the adoption of AF in Germany must be analysed to provide policy recommendations for the creation of an enabling environment for potential AF adopters.

Existing institutional barriers were collated through a literature review. The adequacy of existing funding measures was tested via a Decision Analysis (DA) approach. For this, an existing AF system was modelled, conceptually and mathematically. To identify decision-relevant factors and quantify them, various experts were consulted, and their knowledge supplemented by the available literature. Using value ranges for all the variables allowed for the explicit expression of uncertainty in the model inputs. A Monte Carlo simulation was conducted to compare the net present values (NPVs) of the AF system and the baseline system. A sensitivity analysis was used to identify key uncertainties. Finally, a pairwise comparison of the NPV of the baseline system and the NPV of the AF system across various funding scenarios was conducted to highlight the impact of the funding on the NPV.

The results indicated a significant potential gain through the implementation of the examined AF system, while a large outcome range indicated a high uncertainty regarding the true outcome of the intervention. Although the AF system outperformed the baseline system in ~67 % of cases, the risk for the generating a net loss remains. Key uncertainties were found in variables regarding the productivity of the tree component of the AF system. Examining the NPV of the decision in 10 funding scenarios revealed negligible effects of the existing funding schemes. Only the scenario based on a funding scheme suggested by German AF stakeholders, showed considerable positive effects. Insufficient funding was therefore identified as a key institutional barrier, alongside the lack of (subsidised) consulting, an overly restrictive AF definition, high amounts of bureaucracy and a lack of legal security because of uncoordinated funding- and nature conservation laws.

This thesis finds that the political environment of Germany cannot be considered enabling to farmers interested in AF practices. To reach national targets, institutional barriers must be addressed, and funding increased to adequate levels. It is recommended to consolidate the suggestions by German AF stakeholders when designing future funding schemes.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AF	Agroforestry
AFP	Agricultural Investment Funding Programme
AECM	Agri-environment-climate measure
BayKompV	Bavarian Compensation Regulation
BB	Brandenburg (including Berlin)

BBgNRG	Brandenburg Neighbor Law
BeRI	Consultation Guidelines
BKompV	Federal Compensation Regulation
BLE	Federal Agency for Agriculture and Food
BMEL	Federal Ministry of Food and Agriculture
BMG	Federal Ministry of Health
BNatSchG	Federal Nature Conservation Act
BW	Baden-Württemberg
BY	Bavaria
BZL	Federal Information Center for Agriculture
CAP	Common Agricultural Policy
CC	Cross-Compliance
CCF	Cumulative Cash Flow
CF	Cashflow
CI	Confidence Intervals
DA	Decision Analysis
DeFAF	Deutscher Fachverband für Agroforstwirtschaft
DirektZahlDurchfV	Direct Payments Implementation Regulation
DLR-RLP	Service Center for Rural Areas Rhineland-Palatinate
EAGF	European Agricultural Guarantee Fund
EAFRD	European Agricultural Fund for Rural Development
EEC	European Economic Community
EEG	Renewable Energy Law
EFS	European Forestry Strategy
ELAN	Barriers to the Establishment and Performance of Various Agroforestry Systems in Lower Saxony
EMV	Expected Maximum Value
EOL	Expected Opportunity Loss
EPA	Ecological priority areas
ES	Eco schemes
ESchV	Bavarian Erosion Protection Regulation
ESS	Ecosystem Services

EU	European Union
EVI	Expected Value of Information
EVPI	Expected Value of Perfect Information
EV|PI	Expected Value Given Perfect Information
FoVG	Forest Reproductive Material Act
FRL LIE/2023	Promotion Directive Agriculture, Investment, Economic livelihood
GAEC	Good Agricultural and Environmental Condition
GAK	Improvement of Agricultural Structures and Coastal Protection
GAKG	Act on Improvement of Agricultural Structures and Coastal Protection
GAPDZV	CAP-Direct Payments Regulation
GehölzSchVO EE	Tree Protection Regulation of the Elbe-Elster district
Ha	Hectares
HMLU	Hessian Ministry for Agriculture, Environment, Viticulture, Hunting and Homeland
IACS	Integrated Administration and Control System
InVeKoSV	Regulation on the implementation of support measures and the integrated administration and control system
IQR	Interquartile Range
LEADER	Liaison Entre Actions de Développement de l'Économie Rurale
LEL	State Institute for Agriculture, Nutrition, and Rural Affairs
LM MV	Ministry for Climate Protection, Agriculture, Rural Areas, and Environment of Mecklenburg-Western Pomerania
LOESS or LOWESS	Locally Weighted Scatterplot Smoothing (regression)
Max.	Maximum
MF	Ministry of Finance of Saxony-Anhalt
MKLU	Ministry for Climate Protection, Agriculture, Rural Areas, and Environment of Mecklenburg-Vorpommern
ML Nds.	Lower Saxony Ministry for Food, Agriculture, and Consumer Protection
MLLEV	Ministry of Agriculture, Rural Areas, Europe, and Consumer Protection of the State of Schleswig-Holstein
MLR	Ministry of Food, Rural Affairs, and Consumer Protection of Baden-Württemberg

MLUK	Ministry of Agriculture, Environment, and Climate Protection of the State of Brandenburg
MLV	Ministry of Agriculture and Consumer Protection of the State of North Rhine-Westphalia
Min.	Minimum
MS	Member States
MUKMAV	Ministry of Environment, Climate Protection, Mobility, Agriculture, and Consumer Protection of Saarland
MV	Mecklenburg-Western Pomerania
MWL	Ministry of Economy, Tourism, Agriculture, and Forestry of the State of Saxony-Anhalt
NI	Lower Saxony (including Bremen and Hamburg)
NIPALS	Non-Linear Iterative Partial Least Squares
NPV	Net Present Value
NRW	North Rhine-Westphalia
OL	Opportunity loss
PLS -	Projection to Latent Structures regression
SMR	Statutory Management Requirements
SN	Saxony
SP	Strategic Plan
SRC	Short rotation coppice
STMELF	Bavarian State Ministry of Food, Agriculture, Forestry, and Tourism
TFEU	Treaty on the Functioning of the European Union
TH	Thuringia
TLVWA	Thuringian State Administration Office
UFZ	Helmholtz Centre for Environmental Research
UK	United Kingdom
VIP	Variable Importance in the Projection
VNP	Bavarian contractual nature conservation programme
VoI	Value of Information
WHG	Water Resources Act

1. Introduction

The integration of woody perennials into agricultural systems is considered by many to bear a high potential for increasing the overall services provided by agriculture. Enriching agricultural fields with e.g. fruit bearing shrubs or timber and/or nut producing trees is one of the many ways to combine the production of annual crops and/or livestock with tree-based production. Such systems are referred to as agroforestry (AF) systems. Modern AF systems aim to incorporate ecological principles into agriculture, profiting from ecosystem services (ESS), which may benefit crop and livestock production. Simultaneously, the economic viability of the farming operation is to be maintained.

Since the 2023 reform of Europe's Common Agricultural Policy (CAP), Germany has implemented a legal definition for AF in its national legislation. By the definition given in § 4 (1) GAPDZV[1], AF is now recognised as a form of agricultural land use eligible for basic payments of the CAP. Additionally, the maintenance of such systems can be funded under the eco scheme (ES[2]) programme if certain requirements are met. Despite providing farmers with a legal framework, which is supposed to make harvesting trees from AF systems possible, the number of newly registered AF plots and the demand for the respective ES have been low. The Federal Ministry of Food and Agriculture (BMEL) estimated that in 2023, 25,000 ha of AF would be registered under ES 3, "Maintaining agroforestry management on arable land and permanent grassland". In reality, only 51 ha have been realised (BMEL, 2023f). This implies that Germany may fail to meet its goal of implementing 65,000 ha of AF by 2027 (BMEL, 2023g). This goal in its own is an almost tenfold decrease to the goal set in 2022, which was to fund 625,000 ha of AF until 2027 (BMEL, 2022, p. 441). As a reaction to the low adoption of ES 3 by farmers, the annual funding was increased in 2024 from 60 to 200 € per ha of wooded area. However, the increase is considered insufficient by AF stakeholders such as the German AF association (Deutscher Fachverband für Agroforstwirtschaft, DeFAF). This is particularly because payments for all ES, not just AF, were increased. Other ESs that demand less management effort but provide less environmental benefit are thereby likely to maintain a comparatively higher demand (Böhm, 2023). Consequently, these adjustments do little to encourage the adoption of AF in Germany.

The potential societal benefits AF can provide are institutionally recognised and the extension of AF practices within Germany's agricultural landscape is at least desired at the political level. One strong indication of this is the setting of such high targets, combined with the repeated mention of AF in the German CAP Strategic Plan (SP). The CAP strategic plans, designed by

[1]CAP-Direct Payments Regulation (GAPDZV) of January 24, 2022 (Federal Law Gazette I p. 139, 2287), last amended by Article 1 of the Regulation of December 4, 2023 (Federal Law Gazette 2023 I No. 343).
[2]§ 20, The Common Agricultural Policy Direct Payments Act of July 16, 2021 (Federal Law Gazette. I p. 3003; 2022 I p. 2262).

the European member states (MS) are an addition to the latest CAP reform. Each MS was required to outline their agricultural policy objectives, including how CAP funds are to be used to achieve common European goals. The designing of these plans allows for MS to tailor national policies and strategies to regional needs and challenges. Within the German SP several ESS provided by AF are recognised. An incomplete list would include carbon sequestration (BMEL, 2024, p. 46, p. 200), reduction in nutrient leaching (BMEL, 2024, p.112, p. 241), climate change adaptation (BMEL, 2024, p. 199) and the promotion of agricultural biodiversity (BMEL, 2024, p. 284).

The total area of AF in Germany exceeds the number of AF hectares (ha) funded through ES 3. As of December 2023, 1,304 ha of AF were verified by DeFAF. (DEFAF E.V., 2023). This is over 25 times more than what has been registered as ES 3 in 2023. This points to the inadequacy of the design of this funding measure. The pioneering farmers had financed the implementation of their AF systems without the help of European fundings, or had to find workarounds to maintain the agricultural status of their AF systems in order not to lose basic payments. (CHALMIN, 2022) presents multiple ways, in which farmers have managed to fund the establishment and maintenance of their AF systems. Especially private entities such as companies, foundations or private individuals have supported AF pioneers by providing donations or even sponsorships for individual trees. However, to achieve a landscape-scale transformation of Germanys agriculture, a systematic, political effort, utilising European funds to provide adequate subsidies is needed.

The CAP may be an effective tool for influencing agricultural production, thereby shaping landscapes. With its entry into force in 1957, the main goal of the CAP was to increase agricultural productivity, accelerating the already ongoing process of intensification and industrialisation of agriculture (PETRICK, 2008). Only in 1992 environmental concerns were included into the CAP, leading to the introduction of agri-environmental measures, incentivising farmers e.g. to shift to organic production or other more extensive forms of farm management (FOLMER ET AL., 1995). Today, the CAP is presented as a means of making European agriculture greener and more sustainable (BMEL, 2023c). There has been a strong increase in certain cultivation practices in Germany, e.g., the use of overwintering cover crops has increased by 43 % between 2009 and 2022 (measured in terms of the area cultivated) (DESTATIS, 2024). This can also be attributed to the introduction of so-called "Greening", introduced in the CAP reform of 2013, which meant that 5 % of a farm's arable land had to be designated as an ecological priority area (BLE & BZL, 2018). The cultivation of catch crops was considered such a measure and was favoured over measures such as the cultivation of grain legumes (KIVELITZ, n.d.). KATHAGE ET AL. (2022) confirm this finding with a survey of 407 cover crop cultivating farmers from France, the Netherlands, Romania, and Spain. The authors find that the main reason for the use of cover crops for most respondents is the respective

CAP funding measure or the reduction of basic payments in the event of non-compliance. Even though these changes are due to the imposition of guidelines onto farmers and a bottom-up approach based on the intrinsic motivation farmers may foster towards more sustainable outcomes, the CAP's impact on farmers behaviour is evident. This potential to influence the agricultural practices must be utilised when national AF targets are to be reached. This can ensure the contribution to European Union (EU) goals and environmental programmes, such as the EU Green Deal. However, creating an enabling environment, allowing for farmer-led changes is crucial. The aforementioned pioneering work of German agroforestry farmers demonstrates the interest in implementing agroforestry practices, which must be supported.

Regulations on support for rural development of the EU Parliament and/or Council, have been suggesting the promotion of AF since 2005. In the newest Regulation (EU) 2021/2115[3], AF is mentioned as a sustainable farming practice which can contribute to a climate resilient food production sector. For this reason, the establishment of AF systems can be subsidised by up to 100 %. MS are encouraged to support the establishment of new, as well as the restoration of existing AF systems in their rural development plans (I (26), (72), (73); Art. 15, (2), Regulation (EU) 2021/2115). MS can therefore include funding measures for AF in their national or regional rural development programmes, which are co-financed by the European Agricultural Fund for Rural Development (EAFRD). In Germany, the rural development plans and therefore all funding from Pillar II of the CAP is subject of the Länder, i.e., the federal states. The 16 German Länder make up 13 funding regions, with Lower Saxony, Hamburg, and Bremen as well as Brandenburg and Berlin being merged into one funding region each. Although several regions have introduced investment support measures for establishing AF systems in 2023, their impact is yet to be observed. An ex-ante evaluation of the effect of newly introduced funding measures is therefore pursued in this thesis.

To examine the effects of the introduced funding schemes on the overall profitability of AF systems, a Decision Analysis (DA) approach (LUEDELING & SHEPHERD, 2016) is used. By analysing all factors relevant to the binary decision whether to implement a certain AF system, a decision-supporting model is created. First the decision is conceptually modelled and later translated into a mathematically model. The system examined in this thesis is an existing AF system in the north-west of Germany, which combines arable agriculture with the extensive production of table apples for direct selling. DA can support intricate decisions like this, particularly when observational data is limited. This is because the DA approach aims to integrate the existing state of knowledge associated with the examined decision in its entirety.

[3]Regulation (EU) 2021/2115 Of the European Parliament and of the Council of 2 December 2021 establishing rules on support for strategic plans to be drawn up by Member States under the common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing Regulations (EU) No 1305/2013 and (EU) No 1307/2013

That means collecting literature data but importantly also considering local knowledge as well as expert estimations. After identifying the decision, a conceptual model encompassing all decision-relevant aspects is formulated. It acts as the qualitative basis, which provides an overview of benefits and downsides of the intervention. Here, the target outcome metric is the net present value (NPV) of the system, as an indicator of system profitability. Because of that, input variables which affect monetary in- and outflows (i.e. Cashflow, CF) are regarded as decision-relevant. Thereby, many important ecological effects and services provided by AF systems may be ignored. However, the target of this thesis is the examination of the adequacy of funding measures to compensate farmers for the additional management effort and/or the income foregone as a result of the intervention. The variables captured within the conceptual model are then quantified. This involves assigning value ranges to each input variable and attributing probability distributions to them. A mathematical model, capturing the relationships between the variables and ultimately the impact on the outcome variable, is then formulated. By utilising a probabilistic simulation approach, i.e., Monte Carlo simulations, the variability of the input variables as well as the uncertainty associated with them is captured. The simulation outcome is presented as a distribution. Although not determining specific outcomes of the intervention, a decision-supporting, probabilistic output is provided. This serves above all to reduce the uncertainty inherent in the decision-making process and not to make false predictions, based on singular data. The available funding, whether it be investment support or an annual subsidy, is considered decision-relevant. Holding other factors constant (ceteris paribus) and altering funding-related variables, allows for analysing the influence of existing funding options on the decision outcome. A subsequent sensitivity analysis provides insights into key variables, which affect the outcome metric most significantly. This acts as the basis for the refinement of the model and as a reference for the allocation of resources to further reduce the uncertainty attached to the decision.

Although considered highly relevant, the extent of funding is not the sole factor influencing the adoption of AF among farmers. HERNÁNDEZ-MORCILLO ET AL. (2018) summarise findings from 42 workshops with a total of 665 stakeholders, discussing barriers to the adoption of AF and possible solutions. The authors find that, besides reliable financial support, the lack of knowledge surrounding the design, establishment and management of AF systems was by many stakeholders considered to be the greatest obstacle. The identification of institutional barriers and their impact on the adoption of AF is crucial for the composition of a purposive strategy on the extension of AF practices across Germany. Targeted policies and subsidy schemes must consider all obstacles to lead to the intended results. Before the latest CAP reform, HÜBNER ET AL. (2020) collated 20 institutional barriers to the adoption of AF in Germany. Recording changes under the new CAP is important to highlight which hurdles have been removed and remaining old and potential new ones exist today.

This thesis aims to contribute to the development of adequate funding measures for AF in Germany by demonstrating the impact of several existing and constructed funding measures on the profitability of an AF system. An overview of the history of the CAP is provided, highlighting the changes of overarching goals within the CAP and other EU land use policies. This helps to understand which EU directives address AF and what role this did and could play in the orientation of German funding policy. An emphasis is put on the current existing institutional barriers as well as funding options presently available in Germany. This serves as an introduction to the subsequent case study, in which an existing AF system is examined using DA and probabilistic modelling. In this case study, the effect of the integration of apple trees into an arable operation is assessed in terms of the change in NPV. Additionally, this basic model is used to simulate different funding scenarios to highlight the effects of funding measures onto the decision-making process and the outcome value of interest. By comparing different existing funding scenarios, the adequacy of current German policy is addressed. Testing the effect of constructed funding measures provides a further indication of what adequate funding must encompass and how this could encourage farmers to adopt AF. To highlight the effects of institutional barriers and funding options on agroforestry system profitability, the thesis focuses on the following specific objectives:

A) identify the position of AF in European and German policies, focusing on the CAP, highlighting temporal changes in chronological order.
B) identify present institutional barriers to the implementation of AF in Germany. Collate available German AF funding options and compare them to support measures demanded by AF stakeholders.
C) use a Decision Analysis approach to model an existing AF system. Use the model to illustrate the impact of the funding measures described in B) on the NPV of the modelled decision. Subsequently, identify key uncertainties using sensitivity analysis.
D) formulate recommendations for action for policy makers, responsible for the introduction of future support measures.

2. Theoretical framework: European policy and Agroforestry

2.1. The Common Agricultural Policy of the European Union

The history of the EU and its agricultural policies is characterized by changes and reforms, reflecting changes in overarching objectives. The CAP can be considered as old as the European Economic Community (EEC) itself, which would later become the EU. In 1957, the Treaty establishing the European Community, included in Article 3 the order to introduce a “common policy in the field of agriculture” (EUROPEAN ECONOMIC COMMUNITY, 1957). This treaty was later consolidated and renamed to “Treaty on the Functioning of the European

Union" (TFEU). Despite the change in name, the goals of the CAP, proclaimed in Article 39 of the TFEU, remain unchanged (although not without extension) (EUROPEAN UNION, 2016). The objectives of the CAP were and are to boost agricultural productivity, ensure a fair standard of living for the agricultural community, stabilize markets, guarantee supply availability, and maintain reasonable consumer prices. Environmental protection was not part of the CAP in its early years (WEINGARTEN & RUDLOFF, 2020).

The CAP came officially into force in 1962, initially focused on addressing hunger and increasing food security (PETRICK, 2008). This was done by promoting the mechanisation and industrialisation of farming. An essential part of the CAP at the time was the regulation of markets, ensuring min. prices for agricultural goods which were significantly higher than global market prices (WEINGARTEN & RUDLOFF, 2020). The incentivised production led to the EEC becoming a net-exporter of many agricultural goods. The high level of price support led to an overproduction of e.g. dairy products and cereals. The guaranteed purchase of these products by the EEC resulted in high budget expenditures (73 % of overall EU budget in 1985) (TANGERMANN & CRAMON-TAUBADEL, 2013). In the 1970s the introduction of a compensatory allowance for farmers in "disadvantaged" areas (because of e.g. site conditions), brought aspects of social equity into the CAP (WEINGARTEN & RUDLOFF, 2020).

1992 marked the year of the "MacSharry"-reform, which began to turn the CAP from an income-oriented policy to a market-oriented one. Existing market regulations for e.g. cereals, beef, and lamb were significantly modified. Min. prices for cereals were decreased, while introducing area-based "compensatory payments" (FOLMER ET AL., 1995). Farms had to take parts of their land out of production, the extensification of livestock production was incentivised. This was accompanied by a support for other environmentally-friendly production methods and afforestation (WEINGARTEN & RUDLOFF, 2020). The MacSharry reform is regarded as a first step to promoting ecological sustainability and liberal trade, which led to the linkage of intra-EU and world market prices (FOLMER ET AL., 1995).

The "Agenda2000", introduced in 1999, prepared for the eastward enlargement of the EU (GALLOWAY, 1999; WEISE ET AL., 2001). The accompanying CAP reform aimed to further pursue market orientation. The compensatory payments were now called "direct payments". The reform also introduced "Pillar II" into the CAP, which encompassed the agri-environmental and rural development policies present at the time, thereby highlighting them explicitly. Pillar I encompassed the market- and price policies (WEINGARTEN & RUDLOFF, 2020).

In 2003 the integration of environmental goals into the CAP was enhanced. Within the funding period of 2000–2006, 2003 is referred to as the "mid-term-review". It is considered to be one of "the most radical reforms" up until this point (SWINNEN, 2008). It is also referred to as the year of the "Fischler reform". It set the framework for the CAP until 2013 (WEINGARTEN, 2024).

It gave MS greater autonomy in determining national agricultural policies. MS did now design agri-environmental programmes independently but had to couple direct payments to the fulfilment of certain environmental standards (Cross-Compliance, CC) (OSTERBURG, 2002). CC mandated compliance with 18 EU directives and regulations, spanning environmental protection, human and animal health and welfare, as well as ensuring agricultural land remained in a Good Agricultural and Environmental Condition (GAEC). Violations could lead to penalties or reductions in direct payments (WEINGARTEN & RUDLOFF, 2020). Alongside CC another mandatory instrument called "modulation" was introduced with the Fischler reform. It refers to the shift of funds from Pillar I to Pillar II, by reducing subsidies for larger farms. The last year of the funding period brought further strengthening of Pillar II by introducing EU Regulation 1698/2005[4]. This regulation laid down rules for the support of rural development financed by the EAFRD, established in Regulation 1290/2005[5]. Regulation 1698/2005 included 4 focus points for funding; Improving the competitiveness of agriculture and forestry; Improving the environmental and landscape conditions; Improving quality of living in rural areas and diversifying the rural economy; LEADER[6]. The last point refers to the implementation of local development strategies in which so-called local action groups play a central role (WEINGARTEN & RUDLOFF, 2020).

2008 is referred to as the "Health Check". It led to a reform, which essentially affirmed the Fischler reform by e.g. increasing the modulation, i.e. the redistribution of financial resources from Pillar I to Pillar II. That was supplemented by the "progressive modulation", which meant an overproportioned shortening of subsidies for large agricultural holdings. This was considered necessary to tackle "new challenges" of the agenda, such as climate change, renewable energies, water management and biodiversity (TIETZ, 2010).

In 2014–2020 a key addition to the CAP has been the "Greening" of direct payments. Direct payments were not only coupled with meeting the requirements of CC but furthermore with additional agri-environmental standards. A third of direct payments to conventional farmers have been tied to those standards, which e.g. included the cultivation of min. 2–3 main crops, the maintenance of permanent pasture and the designation of ecological priority areas (EPA) (WEINGARTEN & RUDLOFF, 2020). This was meant to counteract the trend of monotonous crop rotations and the decline of biological diversity in the agricultural landscape. Greening and CC were meant to bring a positive ecological effect to the use of Pillar I resources and applied to

[4]Council Regulation (EC) No 1698/2005 of 20 September 2005 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD)

[5]Council Regulation (EC) No 1290/2005 of 21 June 2005 on the financing of the common agricultural policy

[6]Liaison Entre Actions de Développement de l'Économie Rurale (LEADER) is the EU's participatory approach to involving the rural population in community-led local development through local strategies, projects and decision making processes (WEINGARTEN & RUDLOFF, 2020)

all EU farmers alike. Pillar II measures varied across MS, since these nationally co-financed measures had to be adjusted to MS-specific circumstances. However, the MS had to adhere to the guidelines of the EU, i.e. at least 4 of 6 defined priorities, while formulating their Pillar II strategy. These included e.g. knowledge transfer, conservation and restoration of ecosystems dependent on agriculture and social inclusion, poverty reduction and economic development (NÈGRE, 2022). The EU offered a “menu” of measures MS could choose from, which can be found in EU Regulation 1305/2013[7]. One of the listed measures, namely the Agri-Environment-climate Measure (AECM) has been mandatory to include, since it was considered essential for the environmental goals of the EU at the time. AECM was a broadly described framework rather than a specific measure. This allowed for the independent development of measures by the MS. These could be supported over the funding period, or, where considered necessary, even longer (NÈGRE, 2022).

The period of 2021–2023 marks a transitional period. The EU parliament, council and commission had agreed in 2021 to further reform the CAP for which MS had to prepare their specific SP. Former CAP rules and regulations were extended until the end of 2022, to provide the necessary time for MS to create the SPs. These SPs are one of the major changes regarding the latest CAP reform in 2023 (LAMPKIN ET AL., 2020).

The funding period most relevant in the context of this thesis has started in 2023 and is at this point ongoing until 2027. The basic 2-pillar structure of the CAP remains the same with Pillar I still being responsible for direct payments while Pillar II focusing on environmental measures and rural development. Nonetheless, important changes have been made to certain parts of the CAP. The detailed SPs list how MS will support farmers and other rural stakeholder, how much money will be allocated to certain objectives and what measures will be funded in order to meet EU objectives. The SP is supposed to emphasise results and performance over specific measures. Since the SPs had to be approved by the EU Commission, they had to align with EU ambitions, such as the European Green Deal, the Farm to Fork Strategy and the European Biodiversity Strategy (EUROPEAN COMMISSION, 2022).

An important change made is the introduction of the “green architecture” of the CAP. The obligations of CC and a significant part of Greening are transferred to the “extended conditionality” and are no longer listed separately (Fig. 1). This extended conditionality consists of the 9 GAEC standards and the Statutory Management Requirements (SMR), which entail the compliance with EU regulations regarding public- and plant health, animal welfare and environmental protection. Compared to the previous funding period, farmers must comply to

[7]Regulation (EU) No 1305/2013 of the European Parliament and of the Council of 17 December 2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) and repealing Council Regulation (EC) No 1698/2005

stricter environmental standards, to receive the full basic payment. Since the direct payment has been decreased, farmers must choose from a catalogue of voluntary environmental measures, called Eco Schemes, to maintain the same level of direct payments. These measures are funded by 25 % of the Pillar I direct payment resources (BMEL, 2023b).

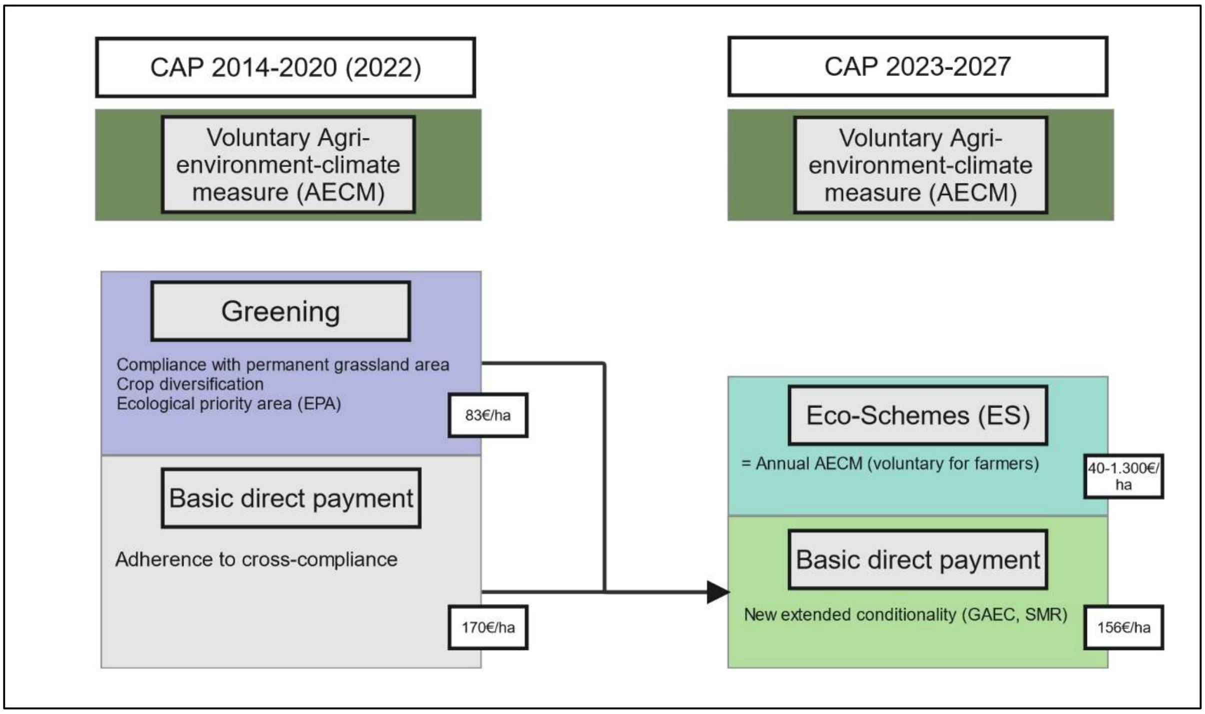

Figure 1: Fundamental changes of the direct payment scheme of the CAP introduced by the latest reform in 2023. Adapted from JANS-WENSTRUP (2024).

The AECMs and ES are meant to be complementary. Although both ES and AECMs were to be developed by the MS, the EU released a catalogue of agricultural practices, which ES could support and MS could integrated into the SPs (EUROPEAN COMMISSION, 2021b). While ES differ between MS, they apply in every federal state of Germany equally. Since the administration of Pillar II finances is handled by the federal states/funding regions, the AECMs differ between them. This ensures further fitting of measures to local conditions (BMEL, 2023b).

2.2. Agroforestry in European Policy:

2.2.1. Agroforestry and the European Forest Strategy

Prior to the existence of the European Forest Strategy (EFS), AF can be found in the context of European legislation as early as 1986. In the Resolution on Community Action in the Forestry sector. It discussed the conversion of agricultural land into forest land, which was meant to lower agricultural production. This was to decrease the self-inflicted overproduction. Additionally, reafforestation was regarded as an integral part of regional programmes aimed at better soil use. “Mixed agroforestry” was in this context mentioned as a transitional stage on the way from agricultural land to forest land (COUNCIL OF THE EUROPEAN COMMUNITIES, 1986).

The EFS mentions AF in 1998 as a multifunctional management technique of forests and "the optimisation of agro-forestry systems" was considered one of the priorities (COMMISSION OF THE EUROPEAN COMMUNITIES, 1998). Within the context of forestry research, "agro-sylvo-pastoral" [sic] systems were seen as a way of diversifying forestry by creating systems which extend the forestry product range. The maintenance of traditionally managed "silvo-pastoral systems" by forest managers was encouraged, as these systems were associated with high levels of biodiversity and carbon sequestration. Despite AF systems being mentioned multiple times in the 1998 EFS, they were absent from the 2005 evaluation of the strategy (COMMISSION OF THE EUROPEAN COMMUNITIES, 2005).

The same pattern was repeated with the EU Forest Action Plan of 2006 and its evaluation in 2012. The EU Forest Action Plan suggested the promotion of AF system by the MS with support from the EAFRD (COMMISSION OF THE EUROPEAN COMMUNITIES, 2006). The "Ex-Post Evaluation of the EU Forest Action Plan" of 2012 did not mention AF (PELLI ET AL., 2012). In 2013 the European Commission suggested in their new EFS, for MS to prioritise certain topics when deciding on allocating resources for forestry related investments. Such topics were e.g. the environmental value and mitigation potential of forest ecosystems, achieving nature and biodiversity objectives as well as creating new woodland and "agro-forestry" systems (EUROPEAN COMMISSION, 2013).

In 2015, the "Multi-annual Implementation Plan of the new EU Forest Strategy" pointed out, that AF is fundable via Pillar II of the CAP and MS can choose to include AF into their rural development plans (i.e. their Pillar II funding plans), referring to EU Regulation 1305/2013 (EUROPEAN COMMISSION, 2015). This regulation states in article 23, that MS may support the establishment of AF systems, as well as grant an annual premium for a period of 5 years. The max. suggested investment support is limited to 80 % of eligible costs.

In 2018, the mid-term evaluation of the 2013 EFS was released and highlighted the underperformance of MS in funding, among other things, AF systems. It was recommended to increase the exchange and promotion of good practices across and within MS to address this issue and to e.g. lower the administrative burden associated with the mentioned measures (EUROPEAN COMMISSION, 2018).

The newest EFS was published in 2021. It is regarded as the flagship initiative of the European Green Deal and builds on the EU Biodiversity Strategy for 2030. It represents a policy framework which is meant to increase the quality, quantity and resilience of European forest ecosystems (EUROPEAN COMMISSION, 2021c). It contains principles such as the promotion of a sustainable bioeconomy for long-life wood products, the promotion of a non-wood, forest-based economy as well as the afforestation in Europe including planting 3 billion additional trees by 2030. AF is considered a measure which can contribute to reaching the said goals.

Chapter 3.3. of the EFS on the re- and afforestation of biodiverse forests, mentions AF as a measure to extend tree coverage in Europe. In chapter 3.4. on the financial incentives for forest owners for improving the quantity and quality of EU forests, MS are specifically encouraged to set up payment schemes, which reward ESS provided by forest managers, as well as to encourage and accelerate "carbon farming practices, for instance via ES on agroforestry" (EUROPEAN COMMISSION, 2021c). In chapter 5. on research and innovation for improving knowledge on forests it is noted that the European Commission plans on supporting the science-based contributions to reaching "climate neutrality and resilience, biodiversity and sustainable growth". In this context, it is stated, that research on AF and other trees outside the forests will be reinforced (EUROPEAN COMMISSION, 2021c).

2.2.2. Agroforestry and the Common Agricultural Policy:

As the above mentioned "Multi-annual Implementation Plan of the new EU Forest Strategy" suggests, AF can be found within the Pillar II regulations of the CAP. In fact, AF was first introduced to the CAP in the 2005 Council Regulation 1698/2005. This regulation contains the general rules on support for rural development and how resources from the EAFRD are to be allocated. It also defines objectives to which rural development policy must contribute. AF systems are mentioned as a measure targeting the sustainable use of forestry land. Additionally, a definition of AF is given in Article 44, dealing with measures on forestry land. Although the definition states, that AF is a land use system in which trees are grown in combination with agriculture on the same land, the placement of the AF funding within the forestry measures links it closer to forestry than to agriculture. This contradicts today's generally recognised definitions, which regard AF as a predominantly agricultural land use system (LAWSON, 2023).

In the funding period of 2007–2013 the establishment of AF was considered a forestry measure, that was to be supported by the MS rural development plans. 0.2 % of the 7 billion € allocated to the forestry measures were reserved for the AF measure (SANTIAGO-FREIJANES ET AL., 2018). The 7 countries of Cyprus, Spain, France, Hungary, Portugal, Italy and the United Kingdom (UK) planned to implement the AF measure into their national or certain regional rural development plans. Only 5 of those countries (minus Cyprus, UK) implemented the measure. These countries ended up reaching 0.8 (Italy) – 25.6 (Hungary) % of their national targets regarding the implementation of AF. Germany did not include AF into its regional rural development programmes within this funding period (LAWSON, 2015).

For the CAP funding period of 2014–2020, the EU Regulation 1305/2013 was introduced, repealing the respective regulation of the previous funding period. It again mentioned AF at several instances. Measures for rural development were highlighted which MS can integrate to achieve EU goals. Among them the "Establishment of agroforestry systems". The regulation

(1305/2013) states that private landholders as well as municipalities shall be granted support to cover the costs of establishing AF systems. Additionally, an annual premium shall be granted for a max. of five years. A max. investment support of 80 % of eligible cost is determined. AF is additionally listed as a measure, which is of relevance to one or more union priorities for rural development, for its ability to aid in the shift towards a low carbon and climate resilient economy.

As in the funding period prior to 2014–2020, AF systems were defined as land use systems in which trees are grown in combination with agriculture on the same land. MS are free to set a min. and max. limit for the number of trees per ha. The Delegate Act 640/2014[8] however limits the max. tree density for agricultural fields eligible to direct payments of Pillar I to 100 trees per ha. In 2017 the EU Regulation 2017/2393[9] was introduced, amending, among others, Regulation 1305/2013. Article 23, dealing with the funding of AF systems got amended, making not only the establishment of new AF systems eligible for funding but also their regeneration and renovation. In the 2014–2020 funding period, the AF measure was integrated into national or regional rural development plans by 8 MS, namely Spain, France, Hungary, Portugal, Italy, the UK, Belgium, and Greece (LAWSON, 2020). Germany, again, did not specifically fund AF systems in this funding period.

With the 2023 CAP reform, the MS were given more autonomy in terms of the design and implementation of measures. The measures, defined in the SPs must serve the fundamental objectives of the EU. These objectives are defined in EU Regulation 2021/2115, where rules on support were established, that MS had to consider when designing their individual CAP SPs. AF is considered multiple times within the regulation. It is emphasized, that AF systems are to be considered agricultural land by MS, if agricultural activities are continued beneath the trees. AF is mentioned alongside precision farming, agro-ecology and organic farming as a practice that makes it possible to produce high-quality, safe, and nutritious food. For this reason, advisory services, aiding farmers interested in AF are to be provided. Additionally, forestry interventions should, where appropriate, widen the use of AF systems. It is suggested to fund the establishment and regeneration of AF systems up to 100 %. The EUROPEAN COMMISSION (2021a) released a document, suggesting agricultural practices which could be

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[8]Commission Delegated Regulation (EU) No 640/2014 of 11 March 2014 supplementing Regulation (EU) No 1306/2013 of the European Parliament and of the Council with regard to the integrated administration and control system and conditions for refusal or withdrawal of payments and administrative penalties applicable to direct payments, rural development support and cross compliance.

[9]Regulation (EU) 2017/2393 of the European Parliament and of the Council of 13 December 2017 amending Regulations (EU) No 1305/2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD), (EU) No 1306/2013 on the financing, management and monitoring of the common agricultural policy, (EU) No 1307/2013 establishing rules for direct payments to farmers under support schemes within the framework of the common agricultural policy, (EU) No 1308/2013 establishing a common organisation of the markets in agricultural products and (EU) No 652/2014 laying down provisions for the management of expenditure relating to the food chain, animal health and animal welfare, and relating to plant health and plant reproductive material

supported by MS via the ES from Pillar I. AF is listed as one such measure. The ES are meant to be a tool for the CAP to support the targets of the European Green Deal.

The European Green Deal is a set of policy initiatives launched in 2020 with the goals of making the EU the first climate neutral “continent” by 2050. By 2030 at least 55 % less net greenhouse gas emissions compared to 1990 levels are to be achieved. Moreover, 3 billion trees are to be planted in the EU by 2030 (EUROPEAN COMMISSION, 2021a). In addition to the transition to a circular economy based on renewable energy sources, changes are also being sought in agriculture. The EUROPEAN COMMISSION (2019) pledged to work with the MS and stakeholders to ensure that the CAP SPs of the MS are aligned with the European Green Deals goals. The SPs should lead to the use of “land use practices such as precision farming, organic agriculture, agro-ecology, agro-forestry and stricter animal welfare standards” (EUROPEAN COMMISSION 2019). This grouping of measures indicates a results-based approach regarding the transition of EU agriculture.

Within the European Green Deal document (EUROPEAN COMMISSION 2019), other European initiatives, which are integral to it are mentioned. The programmes, e.g. the European Biodiversity Strategy focus on land use and/or agriculture. The Biodiversity Strategy is a comprehensive plan, which targets subjects such as the halt of biodiversity loss and the restoration of natural ecosystems across the EU. It outlines targets and actions to protect and restore nature. The goal is to tackle the main drivers of biodiversity loss, according the Biodiversity Strategy are habitat destruction, pollution and invasive species (EUROPEAN COMMISSION, 2020). The role of agriculture is also discussed. It is encouraged to incentivise farmers to transition to sustainable practices. In addition to the promotion of high-diversity landscape features, hedges and non-productive trees in the agricultural landscape, AF are also emphasised as having great potential to provide “multiple benefits for biodiversity, people and climate” (EUROPEAN COMMISSION, 2020).

In line with the European Green Deal, several MS have introduced measures to support AF in their national SPs. Among them, for the first time, is Germany. Within the CAP SP, AF is mentioned several times as a measure which can contribute to meeting national and European targets. AF is considered as a means of effective carbon sequestration (BMEL, 2024, p. 46, p. 200), as a measure to reduce the dependency on fossil fuels (BMEL, 2024, p. 87, p. 177), a way to reduce nutrient leaching (BMEL, 2024, p.112, p. 241), as a climate change adaptation strategy because of its potential to not only sequester carbon but also provide regulating ESS such as the reduction of wind (BMEL, 2024, p. 199). Furthermore, AF is regarded as a measure which can assist in the sustainable use of water by increasing the water holding capacity of agricultural soils and decreasing evaporation by reducing wind speeds on landscape level (BMEL, 2024, p. 242). AF systems are also regarded as land use systems promoting biodiversity (BMEL, 2024, p. 284). Since AF is associated with this multitude of benefits, it is identified as a measure to be promoted with "high" to "very high priority" (BMEL, 2024, p. 609). In fact, the German CAP SP originally included the goal of funding 25,000 ha of AF in 2023 through the respective ES measure, leading to 625,000 funded ha of AF in 2027 (BMEL, 2022, p. 441). To achieve this, 1 % of the financial resources available the ES measures got allocated to ES 3, which funds the maintenance of AF on arable land and permanent pastures. This meant originally a direct payment amount of 60 €/ha of wooded area for AF systems, which meet the requirements of ES 3 (BMEL, 2022, p. 441). This means, that only the area which was covered by trees and/or shrubs (i.e. the tree rows) were eligible to this premium. This would lead to an overall premium payment of 6 €/ha of AF system, if 10 % of the system consisted of trees/shrubs.

In a press release in June 2023, the Federal Ministry of Food and Agriculture published numbers on the use of the ES according to provisional application data which showed a low adoption of many of the ES (this data was published without prior verification or plausibility checks). It states that out of the 25,000 ha of AF planned to be funded, 51 ha were realised (BMEL, 2023f). As a reaction, the CAP SP was revised and it was acknowledged, that climate change mitigation and adaptation measures were insufficiently implemented, explicitly mentioning AF (BMEL, 2023g, p. 211). the funding amount for several ES got raised. For ES 3, it was raised from 60 €/ha to 200 €/ha of wooded area. At the same time, the targets set in the SP were revised downwards significantly. Instead of 625,000 ha, now 65,000 ha of AF funded through ES 3 are to be reached by 2027. In addition, the budget allocated to ES 3, was reduced by over 82 % from 37,500,000 € to 6,500,000 € (BMEL, 2023g, p. 534).

Germanys CAP SP suggests the implementation of a targeted investment support measure, which would support farmers in establishing new AF systems. This is meant to complement the annual support farmers can receive through ES 3. Such investment support measures are to be integrated as a measure for rural development, financed by the EAFRD (Pillar II). Since in Germany all Pillar II measures are administered by the federal states, no nationally standardised investment support measure will be available to farmers. This offers the opportunity to adapt the funding measure to region-specific needs but led to the fact, that only certain federal states introduced an investment support measure at all. The following will deal with the available funding for AF in Germany, reviewing the ES as Pillar I measures and the federal state-specific investment support measures in detail.

2.3. Currently available funding options in Germany

2.3.1. Pillar I-funding, Eco-Scheme 3: Maintenance of Agroforestry Systems on arable land and permanent pasture

To avoid confusion due to similar English terminology, the terms "Federal Republic (of Germany)" and "Federal state" (i.e. the federal sub-units of Germany) are not used in the following. The terms "Bund" and "Länder" (singular: “Land”) are used instead. This is to ensure a clear differentiation between the two.

Pillar I-funding is entirely determined by the Bund. It is financed via the European Agricultural Guarantee Fund (EAGF) and is used for direct payments and market measures. With the 2023 CAP reform, a new instrument for the ecological enhancement of EU agriculture was introduced into measures funded within Pillar I. These environmentally focused measures are called Eco Schemes, to which 23 % of financial resources for direct payments are dedicated (BMEL, 2023b). Together with the SMR and the AECMs in Pillar II, the ES of Pillar I, build the “green architecture” of the new CAP. The ES are meant to be voluntary measures, farmers can take to increase the amount of direct funding they receive by adopting or maintaining farming practices, which contribute to the environmental and climate goals of the EU. The primary aim of the ES is to enhance biodiversity, with additional considerations towards climate protection. While climate protection is acknowledged within the ES framework, it's not its central focus as there are separate funding streams allocated for this purpose. Germanys CAP SP states, that “investment subsidies required for climate protection initiatives are more effectively channelled through Pillar II” (BMEL, 2024). The ES were officially introduced in 2023 and in 2024 underwent changes due to low demand from farmers. Because of this, the requirements and total funding sums differ in 2024 from what was initially introduced (BMEL, 2023a). To avoid lengthening the following section, the 2023 funding levels are mentioned only where changes were introduced, but the initial requirements of the ES are not specified. Rather, the revised requirements for 2024 are presented.

The 7 available ES, found in BMEL (2023b), are:

- <u>ES 1:</u> “Provision of areas for the improvement biodiversity and conservation of habitats.”.
    - Farmers can choose to turn eligible land into agriculturally non-productive areas (0.1 ha–6 %). These non-productive areas include fallow land (sown or self-seeded) or sown flower strips. More area must be made available than what is required according to GAEC 8 (4 %).
    - Amount of payment:
        - Fallow on arable land:
            - 1st ha (or 1st %): 1,300 €/ha; 2nd %: 500 €/ha; 3rd–6th %: 300 €/ha

        - Flowering strip on arable land and permanent crops:
            - 200 €/ha (150 €/ha in 2023)
        - Unmown strip/area of pasture:
            - 1st %: 900 €; 2nd %: 400 €; 3rd–6th %: 200 €
- ES 2: "Cultivation of diverse crops with at least 5 main crop types in arable farming, including the cultivation of legumes with a min. share of 10 %.".
    - A "main crop" is every crop that is grown on 10–30 % of the arable area of a farm. 10 % of the total arable area must be used annually to grow leguminous crops. Amount of payment: 60 €/ha (45 €/ha in 2023).
- ES 3: "Maintaining agroforestry management on arable land and permanent grassland.".
    - This measure will be described in detail below. Amount of payment: 200 €/ha of tree row (60 €/ha of tree row in 2023).
- ES 4: "Extensification of the entire permanent grassland on the farm.".
    - This measure is process-oriented, meaning that farmers receive the respective subsidy for complying with the associated requirements of ES 4. These requirements include e.g. decreasing the total number of large ruminants per area of permanent grassland as well as the limitation of fertilizer use. Amount of payment: 100 €/ha (115 €/ha in 2023).
- ES 5: "Result-orientated extensive management of permanent grassland with evidence of at least four regional indicator species.".
    - In contrast to ES 4, this measure is result-orientated, meaning that the subsidy payment depends on the condition of the farm's permanent. The requirements are met, if the farmer can prove, that certain indicator plant species are present. Amount of payment: 240 €/ha (240 €/ha in 2023, 225 €/ha in 2025, 210 €/ha in 2026).
- ES 6: "Cultivation of arable land or permanent crops on the farm without the use of synthetic chemical pesticides.".
    - Farmers can register certain fields to receive ES 6 payments and commit to not using pesticides from January 1st to August 31st (or to November 15th for permanent crops or grass mixture crops). Amount of payment: 150 €/ha for arable crops such as grains and maize (130 €/ha in 2023, initially to be reduced to 110 €/ha in 2025 and 2026); 50 €/ha for grass, grass-mixtures and mixtures containing legumes used as fodder.

- ES 7: “Application of land management methods determined by the conservation objectives on agricultural land in Natura 2000 areas.”.
    - Only agricultural fields, situated within Natura-2000 areas are eligible for this payment. Requirements are e.g. to not change water levels by e.g. drainage measures or by backfilling. Amount of payment: 40 €/ha.

The measure of greatest interest for this thesis is ES 3. It is the first national support measure Germany ever offered specifically for AF systems. It is described as a measure, which can support meeting EU goals by fixing carbon in wood, roots and soil, increasing soil fertility by building up organic matter, reducing evaporation through shading and wind protection, reducing the discharge of substances into water bodies and restructuring agricultural fields, adding to a multifunctional landscape (BMEL, 2023b).

The requirements for ES3 build upon the definition of AF in § 4 GAPDZV, which is the regulation, responsible for the allocation of CAP finances in Germany. This definition entails the following:

An AF system on arable land, permanent grassland, or permanent crops:

- must have the primary objective of producing raw materials and/or food crops.
- must be based on a management concept examined and validated by the responsible regional authority.
- must not consist of tree species, listed in the negative list of Annex 1 of the GAPDZV (This negative list is available in Annex I in this thesis).
- must consist of min. 2 tree rows, which make up not more than 40 % of the agricultural field, or
- must consist of a total of 50–200 scattered woody perennial plants (trees and/or shrubs).

Only when an AF system meets these criteria, can it be registered as agricultural land and is eligible for direct payments. Important to note is, that trees, which were formerly (until 31.12.2022) recognised as landscape elements, cannot be considered part of AF systems (§ 4, (3) GAPDZV).

Based on the above definition, the following, more specific requirements for ES 3 are determined. These can be found in attachment 5 Nr. 3 of the GAPDZV. To receive the ES 3 funding, the AF system on arable land or permanent pasture must meet the following criteria:

- must be an alley cropping system, no scattered tree systems are considered eligible for ES 3.

- must contain at least 2 tree rows (or rows of other woody perennials), which make up 2–35 % of the agricultural field. These rows must be “largely continuous with woody vegetation cover.”.
- tree rows must be 3–25 m wide.
- smallest possible distance between tree rows and between tree row and field edge is 20 m. Exception: If a wooded strip is established adjacent to or in the vicinity of watercourses, the distance to the edge may be less than 20 m.
- wood harvest must be only in January, February, and December.

When an AF system, which is registered as such meets these requirements, an annual premium of 200 €/ha of wooded area is granted. The subsidy does therefore vary between 4 and 70 €/ha of AF system, depending on the percentage of wooded area of the system.

2.3.2. Pillar II funding – Länder-specific investment support

The establishment of permanent structures on farms such as the implementation of AF systems, comes not only with a probable increase in management intensity but requires a significant initial investment. Experts on the planning, consulting, agricultural practice associated with AF systems, such as the DeFAF, are correspondingly critical of the predominant lack of investment support for AF in Germany (BÖHM, 2023). The EU regulation 2021/2115 explicitly allows for MS to subsidise the establishment and regeneration of AF systems up to 100%. In addition, the support of AF-related investments is included in the 2023 version of the “Joint Task for the “Improvement of Agricultural Structures and Coastal Protection”” (GAK).

The GAK is “the most important national funding instrument for the support of agriculture and forestry, rural development and improvements in coastal protection” (BMEL, 2023d). The goal of the GAK is to optimize the agricultural and forestry sectors, aligning them with future demands while maintaining competitiveness within the EU’s market. Additionally, it seeks to maintain the long-term efficiency of rural areas, integrating environmentally sustainable practices into agricultural and forestry activities. Moreover, the GAK aims to enhance coastal and inland flood protection measures. A multitude of measures are listed within the GAK-catalogue, which the Länder can then adopt. This opens up the possibility for the Länder to subsidise Pillar II measures with co-financing from the Bund (BMEL, 2023e). Despite this, only 7 of the 13 German funding regions introduced such financial investment support measures. The support ranges from subsidised AF-related consultancy to a funding amount of 65 % of eligible investment costs. These measures are intended to complement the area-based annual AF funding from Pillar I and are meant to support farmers in their endeavours to establish AF systems. The following section presents the investment support measure outlined in the GAK (BMEL, 2023e).

2.3.2.1. Agroforestry investment support in the GAK

The GAK presents a multitude of funding measures, which the Länder can choose to integrate into their regional support plans and thereby access co-financing from the Bund. In 2020, HÜBNER ET AL. criticized the absence of AF in the GAK and, thereby the absence of its recognition as an environmentally sustainable farming practice. However, with the 2023 reform, this has been addressed. The revised GAK now includes a specific proposal for AF investment support, intended to complement the annual, area-based subsidy, thereby enhancing incentives for farmers (BMEL, 2023e).

2.3.2.1.1. GAK Funding Area 4: Market- and Location-Adapted as well as Environmentally Sound Agricultural Practices, including Contract Nature Conservation and Landscape Maintenance

The GAK definition of AF systems eligible for funding is identical to the definition for ES 3 (BMEL, 2023e). Therefore, AF systems with scattered trees or AF systems in permanent crops are not eligible for investment support.

With respect to the tree species, the negative list of trees mentioned for ES 3 applies here too. In addition, care must be taken to ensure that only certified planting material is used if a tree species falls under the FoVG[10]. These include, e.g., the chestnut (*Castanea sativa*) or the whole genus poplar (*Populus)*.

The GAK defines investments for the establishment of rows of trees/shrubs as eligible for funding, but explicitly excludes land purchase, the acquisition of agricultural production rights, investments needed to conform with EU standards and running costs for the management of the AF system. In addition, the government of the Länder can designate areas where AF systems are not eligible under any circumstances because their installation conflicts with other regional objectives such as nature conservation objectives. To receive funding, the farmer must provide proof of ownership over the field, which the AF system is supposed to be established on, or a declaration of consent from the owner. Additionally, a utilisation concept (i.e. a plan indicating the design of the AF system and the intended management), must be provided, which has to be positively reviewed by a competent authority (BMEL, 2023e).

The amount of payment depends on the intended production goal and/or the structure of the system. No specification on what percentage of investment cost can be funded is made. Therefore, the funding of 100 % of the cost up to a certain amount can be assumed. Farmers can receive up to 1,566 €/ha of wooded strip, when planting species intended for short rotation coppice (SRC). Up to 5,271 €/ha of wooded strip can be received, when planting trees to produce food and/or high value timber. This planting can be combined with “shrubs” in the

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[10]Forest Reproductive Material Act (FoVG) of May 22, 2002 (Federal Law Gazette. I p. 1658), last amended by Article 414 of the Regulation of August 31, 2015 (Federal Law Gazette. I p. 1474).

understory. Planting only “shrubs” can be subsidised with up to 4,138 €/ha of wooded strip. No definition of “shrub” is given in the GAK itself (BMEL, 2023e) or the associated act on improvement of agricultural structure and coast protection (GAKG[11]). It can be assumed, that a shrub in the sense of the GAK is a woody perennial, which is neither planted with the intention of a short rotation biomass production nor for the production of timber. If a fruit tree, with a low set crown and a short trunk of e.g. 60–80 cm is considered a shrub or a “tree for food production” is not clearly defined. Upon request, the information was provided, that “bush trees” and “spindle trees” with stems of ~ 60 cm are considered trees and not shrubs (BMEL, personal communication, 5. April 2024). Regardless of the type of AF system that is to be established, a min. funding amount of 2,500 € must be reached before funding can be approved. This means, that at least 0.47 ha of fruit/timber trees or 1.59 ha of SRC must be established, to receive any investment support. The total funding amount is limited to 300,000 € per funding application, so that 191.57 ha, 72.49 ha or 56.91 ha of wooded area can be funded with either SRC, shrubs or trees for food or timber production respectively (BMEL, 2023e).

The GAK contains another programme, which in the CAP SP is associated with the funding on AF investments, namely the Agricultural Investment Funding Programme (AFP). The CAP SP states multiple times, that the AFP can be used to fund the investment costs associated with the establishment of AF systems (BMEL, 2024, p. 183, 456, 1543). As previously established, not the Bund but the Länder are responsible for allocating finances which come through Pillar II. This means, the Länder must at least integrate the AFP into their regional plans in order for farmers of that Land to access the AFP funding. Currently, 11 out of the 13 funding regions offer AFP funding (DLR-RLP, 2024; HMLU, 2023; LM MV, 2023; MF, 2022; ML NDS., n. d.; MLLEV, 2024; MLR, 2022; MLUK, 2022; MLV, 2022; MUKMAV, 2019; STMELF, 2024).

To clarify whether investment support for AF systems is possible via the AFP, 8 of the responsible ministries of the Länder were contacted. Priority was given to the ministries of the respective Länder that do not offer area-based investment support for AF systems through the Funding Area 4 of the GAK. Six of the contacted ministries replied and provided varying levels of information on why AF systems are *not* funded via the AFP. For detailed information on why the Länder do *not* fund the establishment of AF systems through the AFP, please consider Annex II.

2.3.2.2. Bavaria

As the first German federal state Bavaria (BY) introduced an investment support measure for the establishment of modern AF systems. This measure is available from 01.01.2023–31.12.2027. It was introduced in December 2022 in the “Joint guideline on the support of Agri-

[11]GAK Act (GAKG) as amended by the announcement of July 21, 1988 (Federal Law Gazette. I p. 1055), last amended by Article 1 of the Law of October 11, 2016 (Federal Law Gazette. I p. 2231).

environment-climate measures in Bavaria”. While there are two AF related support measures, one relates to the establishment of traditional meadow orchards, a special form of AF system that this thesis does not focus on. “Modern” AF systems can be funded via the subsidy “I84 - Establishment of Agroforestry systems” (STMELF & STMUV, 2022).

The requirements to receive the subsidy are largely identical to the description in the GAK. Additionally, labour input provided by the farmer (and employees) into the establishment of the system is not fundable. The total funding amount is capped at 50,000 € per AF investment instead of 300,000 € and at 65 %. The per ha funding amounts, differentiating between system types, are identical to what is described in the GAK. However, the abovementioned sums are only supplied, if they account for 65 % of the actual cost of the establishment of the tree row. That means, to receive the suggested 1,566 €/ha of wooded area for SRC, the farmer must prove an establishment cost of 2,409.23 €/ha. With the max. funding being capped at 50,000 € per application, a farmer can request support for the establishment of 9.5–31.93 ha of wooded area depending on the type of AF (SRC, shrubs, or food and timber trees) (STMELF & STMUV, 2022).

A farming operation must contain a min. of 3.00 ha of land eligible to direct payments of the CAP to receive GAK funding. Horticultural operations are exempt from this rule, and do not have to meet the min. size of 3.00 ha. Regardless of that, only silvoarable and silvopastoral alley cropping systems are fundable, excluding AF systems in permanent crop fields (STMELF & STMUV, 2022).

Further requirements may apply if an AF system is to be implemented in an area classified as part of the Bavarian contractual nature conservation programme (VNP). In this case, approval from the regional nature protection authority must be obtained before investment support can be granted. Similarly, AF projects in designated flood areas require the authorisation of the local water authorities. Important to note is, that only AF projects can be funded, when the application for investment support is submitted before the AF establishment process has been started. While contacting local authorities (such as nature protection or water authorities) does not count as starting the establishment, concluding a purchase agreement for, e.g., planting material, does (STMELF & STMUV, 2022).

2.3.2.3. Mecklenburg-Western Pomerania

In July of 2023 the Ministry for Climate Protection, Agriculture, Rural Areas and Environment of Mecklenburg-Western Pomerania (MV) introduced their AF investment support measure titled “Directive on the granting of subsidies for investments by agricultural enterprises for the establishment of agroforestry systems” (MKLU, 2023). The directive came into force retroactively and is valid until 31.12.2027. The directive's retroactive validity has no effect, as all measures by farmers regarding AF establishment taken before the funding was officially approved are not eligible for funding. AF systems installed in 2023 up until 14.07.2023 are, therefore, not retroactively fundable (MKLU, 2023).

MV's investment support regulation is largely in line with the BY regulation, as both are based on the GAK. One difference is that no min. size of managed land area is mentioned. Same as in the BY regulation, the funding is limited to 65 % of eligible costs with the same distinction between different AF types (i.e., SRC, shrubs or food and timber trees). MV adopts the max. possible funding amount set in the GAK, namely 300,000 € per AF project (MKLU, 2023). An AF system of a particular design would not be funded any more than in BY. However, the max. funded wooded area per AF project is significantly higher than in BY, with 56.9–191.57 ha wooded area in MV, compared to 9.5–31.93 ha in BY.

2.3.2.4. Lower Saxony (including Bremen and Hamburg)

The federal Ministry of Food, Agriculture and Consumer Protection of Lower Saxony (NI) introduced its investment support measure for AF system establishment in April 2023. It officially came into force on 26.04.2023 and was initially only valid until 31.12.2023. It has been eventually extended until the 31.12.2024.

The "Directive on the Provision of Grants for the Promotion of Agroforestry Systems[12]" offers support up to 40 % of eligible investment expenses with a max. funding sum of 20,000 € per AF project. The eligible expenses mentioned in the regulation are explicitly limited to the purchase of planting material and plant protection material (e.g. fencing or single tree protection). Additionally planting of the trees or shrubs is eligible, provided that the act of planting is carried out by third parties and not the farmer and/or the respective employees themselves. Expenses related to the purchase of agricultural land, the preparation of the establishment area and the maintenance of the AF system are not eligible. Furthermore, expenses related to planning and consulting – although regarded as crucial parts of the AF establishment process by many experts – are explicitly mentioned as not eligible for funding (ML NDS., 2023).

Investment support is solely granted for a farmers first AF system. Additionally, silvopastoral systems are excluded from the support scheme, as only AF systems on arable land are funded. An AF system eligible for investment support must meet the criteria of § 4 GAPDZV and not the extended criteria of ES 3. This means, that systems with scattered trees are not explicitly excluded from funding. Also, the funding amount does not depend on the size of the established wooded area as is the case in BY and MV. Rather, the scope of the subsidy depends solely on the total amount of eligible investment cost per funded AF project.

[12]Directive on the Provision of Grants for the Promotion of Agroforestry Systems (Agroforestry Systems Directive) Issued by the Ministry of Agriculture on April 19, 2023 - 105-29804-3136/2022 - Published on April 19, 2023 (Nds. MBl. p. 316) Amended by Directive on December 11, 2023 (Nds. MBl. p. 1126)

Nonetheless, specific system types are being encouraged and favoured. This is done by capping the overall available funding amount and ranking the applicants AF systems by a specific point system (see Annex III for details) (ML NDS., 2023).

This system replaces the stricter ES 3 requirements farmers must meet in BY and MV for subsidy. For example, no min. size of the cultivated area is specified as a criterion. Rather, farmers with utilisation concepts presenting the highest numbers of points are prioritised for receiving funds. The number of points a utilisation concept obtains, is determined by several factors such as cultivation systems (scattered trees or tree rows), production goal (fruit, nuts, energy wood or timber), size of the AF system, percentage of wooded area and, also, the region in which the AF system is supposed to be established. Unlike in BY, SRC (3 points) are valued higher than food-producing systems (1 point) if the only food produced is fruit. Nut production systems (e.g. walnut or chestnut) are valued the highest (5 points). Systems between 2 and 10 ha are assigned the highest number of points (5 points) as well as systems with 2–20 % wooded area (3 points). Although this makes it more difficult for farms with less than 3.00 ha of eligible area to access the subsidy, it does not completely exclude them, as is the case in BY. Applicants from the north-western and southern regions of NI are automatically assigned 3 points, while applicants from the north and north-east are assigned 2 points. This makes the point system a tool that, allows the NI authorities to promote predetermined landscape configurations by encouraging the adoption of specific AF practices in specific regions. By applying for the investment subsidy, farmers agree to cooperate in the ELAN project of the University of Göttingen, which examines obstacles to establishing and performing different AF systems in NI (ML NDS., 2023).

2.3.2.5. Saxony

Saxony (SN) introduced its investment support measure for the establishment of AF systems in June 2023 as the “Directive (…) on the promotion of Agricultural investments and Economic livelihoods”, (FRL LIE/2023)[13]. Like MV’s regulation, it was made valid retroactively, but only expenses made after applying for the investment support are eligible for funding. Rather than being an AF-specific guideline, FRL LIE/2023 covers support for a multitude of agricultural investments, e.g. greenhouses, digitalisation of management processes and SRC plantations on arable land, which can be considered a specific type of AF.

SN’s regulation explicitly contains an investment support measure for silvoarable AF systems. The investment associated with these systems can be funded up to 40 %. There is no differentiation between system designs, as long as the AF system is established on arable

[13]Directive of the Saxon State Ministry for Energy, Climate Protection, Environment, and Agriculture on the Promotion of Agricultural Investments and Economic livelihoods (Promotion Directive Agriculture, Investment, Economic livelihood – FRL LIE/2023) Dated 20.06.2023

land. The min. investment support sum is 20,000 € per subsidy application, while the max. is 5,000,000 € for the whole period of 2023–2027. This means, that only projects of a certain min. investment size are funded. With a funding of 40 %, a min. investment of 50,000 € must be proven, to receive funding. Moreover, only enterprises managing more than 8.00 ha of agricultural land, are eligible for funding (FRL LIE/2023).

The enterprise manager must be able to provide proof over sufficient qualifications (i.e. certificate of completed agricultural training). If investment support over 100,000 € is applied for, an advanced accounting for 2 years must be submitted as proof of successful business management. If the subsidy sum exceeds 400,000 €, and the beneficiary is registered as a legal entity, all associates (with a capital share of 25 %) must provide a collateral of 15 % of the subsidy amount through a directly enforceable guarantee. These requirements for large investments especially affect other investments covered in the regulation, e.g. agricultural buildings. Important to note is, that the investment payment is explicitly only carried out once the respective project has been fully implemented and paid for (FRL LIE/2023).

2.3.2.6. Baden-Württemberg

Although Baden-Württemberg (BW) has yet to introduce a regulation dedicated to the support of investments for the establishment of AF systems, it is possible to receive support for what is often considered a crucial part of the establishment process of AF systems, namely planning and consulting. Since April 2023, a subsidised consultancy with a total of 91 advisors can be accessed, 11 of which offer AF consultancy (LEL, 2024). The hourly rates range from 120–150 € and are funded up to 80% with a limit of 1,500 €. At least 5 hours of consultation must be used to receive the funding. Considering the hourly rates and the investment support rate, a min. investment of 600–750 € is necessary to receive any funding, i.e. 480–600 €, respectively (LEL, 2023).

The consultation can include the planning, establishment, and/or management of silvoarable, silvopastoral, and agrosilvopastoral systems and their economic viability. It can also evaluate AF system design regarding biodiversity, climate protection, and climate resilience (LEL, 2022).

2.3.2.7. Brandenburg (including Berlin)

The funding region of Brandenburg and Berlin (BB) does not yet offer an investment support measure for the establishment of AF systems, although the introduction of such measure is planned for 2024 (MLUK, personal communication, 3. April 2024). No information was received on the planned scope of funding, but the scheme is based on the GAK, same as in BY and MV (MLUK, personal communication, 3. April 2024).

Presently, consulting for farmers is subsidised, which, since 2023, includes AF as a consultancy subject. A total of 31 subjects for consulting are offered, that can be individually combined. Six licensed consultants offer AF consulting (Attachment I, BeRI[14]). The funding regions respective Ministry of Agriculture, Environment, and Climate Protection (MLUK), offers a total of 18 subsidised consulting hours, calculating with an hourly rate of 85 €/h. This way, a total funding of 1,530 € can be achieved (MLUK, personal communication, 2. April 2024). The farmer can choose a combination of topics as well as the consultant. The consultancy must, however, contain a site visit of min. 2 h. In total, at least 25 % of the consultancy must take place on site at the farm. 75 % of consultancy may be used for preparation and follow-up work as well as for remote counselling (MLUK, 2024).

2.3.2.8. Thuringia

Similarly to BW and BB, Thuringia (TH) offers only investment support through subsidised AF consultancy. In 2023, 3 consulting agencies could be accessed and the max. funding amount was 1,500 € (TLVwA, n.d.-a). No other limitation, such as only funding a certain percentage of consulting cost, is mentioned. This AF consultancy funding fell under the funding for “Ecosystems, green Infrastructure”, which encompassed all agricultural practices that “benefit the climate and the environment, ecosystem services and green infrastructure”, including production-integrated measures such as AF (TLVwA, 2021).

For the period of 2024–2027 a new funding measure was established. While the funding still supports consulting exclusively, there has been an expansion in the spectrum of counselling services available, accompanied by an increase in the accessible consulting agencies to 4 instead of 3 and an increase in max. funding to 2,000 € per consultancy (TLVwA, n.d.-b).

There are three specific AF-related consulting subsidies described for TH. Firstly, “Los Nr. 25 – Agroforestry Systems – Rough Conception”. The funded consultation must cover: a comprehensive site and farm analysis, advice on farm-specific goal formulation, selection of suitable systems for the individual farm concept, selection of suitable areas, examination of possible usable processing and marketing pathways, labour-economic plausibility check and economic forecast, initial assessment of the relevant legal framework conditions and funding opportunities, detailed indications of possible sources of errors.

Secondly, “Los Nr. 26 – Agroforestry Systems – Detailed planning”. It must encompass the selection of species and varieties appropriate to the location and use, preparation of detailed site-specific planning (utilising digital tools), the development of a management and utilisation concept, comprehensive information on nature conservation aspects, along with labour-

[14]Directive of the Ministry of Agriculture, Environment, and Climate Protection of the State of Brandenburg for the Promotion of the Utilization of Agricultural and Horticultural Consulting Services and for the Establishment of Consulting Enterprises, 21.11.2023

economic clarification and an economic calculation of long-term profitability (cost-benefit analysis).

The third subsidy for AF consulting is titled “Los Nr. 27 – Agroforestry Systems – Establishment and Management”. It must encompass at least three of the following points. Development of a work and time schedule, field measurement of the wooded area using GPS systems, preparation and/or implementation of the ordering of planting material, selection of suitable planting techniques, assistance in implementing protective measures against e.g. deer browsing, development of an individual monitoring plan and the development and support of optimisation options in existing systems (TLVwA, n.d.-b).

The subsidy is set at 2,000 € per consulting service used. With farmers having the flexibility to engage in subsidized consultations across various listed topics. Given that three of these topics pertain to AF, a max. funding amount of 6,000 € can be secured for AF advisory services (TLVwA, personal communication, 28. March 2024).

2.3.2.9. AF funding as suggested by DeFAF

In 2023, DeFAF released an open letter, addressed to ministers and senators for agriculture and the environment of the German government and the Länder as well as the members of the Bundestag committees "Food and Agriculture" and "Environment, Nature Conservation, Nuclear Safety and Consumer Protection" (Böhm et al., 2023). In this open letter, which was co-signed by 100 stakeholders from agricultural and nature conservation organisations as well as scientists and individuals from civil society, an urgent request regarding the funding of AF systems in Germany has been made. Böhm et al. (2023) suggest to significantly increase existing annual payments as well as the introduction of a national investment support scheme for farmers to implement AF systems. In addition, they push for the removal of bureaucratic hurdles such as specific distancing regulations and the need for the provision of a management concept. An increase of ES 3 from 200 €/ha of wooded area to at least 600 €/ha of wooded area is strongly suggested. It is added, that the annual support for the first 10 ha of wooded area should be “significantly higher than this”. However, Böhm et al. (2023) do not specify this further. In addition, the authors suggest allowing for the combination of ES 3 and ES 1, encouraging the establishment of AF systems with productive woody components but an otherwise extensive management of the rest of the tree row. A differentiation between the type of wooded area is proposed, with more diverse systems, including more species of woody plants being subsidised more than simpler systems (Böhm et al., 2023).

A complementary investment support scheme should fund 100 % of the first 10 ha of wooded area. Every next ha, up to 20 ha in total, shall be funded 80 %. Every ha after that shall be funded 50 %. No differentiation between different costs has been made, indicating, that every direct investment cost shall be regarded as eligible for funding. This way, a significant encouragement for farmers to implement AF systems would be created and national targets could be realised (Böhm et al., 2023).

2.4. Institutional barriers for the adoption of Agroforestry in Germany

With the introduction of a legal definition of AF, one major obstacle that could prevent farmers from planting trees in their fields has been removed. Without the legal definition, trees on farms were regarded as landscape features, except for permanent crops such as fruits and nuts or SRC plantations in separately registered plots. The removal of such landscape elements is not permitted (see GAEC 8 of the newest CAP, GAEC 7 in CAP 2014-2020), which is why it is important for farmers to consider the design requirements that exists for AF systems in Germany today. The definition according to § 4 GAPDZV, as well as ES 3, and the associated requirements are presented in detail in 2.3.1. Even after the introduction of a legal framework, within which famers can operate, i.e. manage, and harvest AF systems, legal barriers remain. The following will present institutional barriers to the adoption of AF systems, which existed before the newest CAP reform and will investigate their status as well as the introduction of new barriers.

HÜBNER ET AL. (2020) collated 20 institutional barriers as well as suggestions for solutions and possibilities of avoiding the obstacles by clever system design, for the period of 2014–2020. Most of these barriers can be divided into 3 broad categories:

1. Lack of a definition of AF in national legislations.
2. Restrictions for tree plantings.
3. Ecological potential of AF is disregarded, therefore not renumerated.

The subsequent section will focus on the obstacles considered to be most relevant, ensuring comprehensive coverage of existing barriers while maintaining brevity and reader engagement. Should a detailed commentary on all 20 institutional barriers compiled by HÜBNER ET AL. (2020) be of interest, see Annex IV.

2.4.1. Lack of a definition of AF in national legislation

Up until 2023, AF systems were not recognised as a formal land use unit. This meant, that trees on agricultural land were regarded as protected landscape features, which remained eligible for direct payments but could not be productively managed or removed. This led to the creation of workarounds, farmers had to use to integrate trees as productive elements into their agricultural fields. Eight of the 20 institutional barriers HÜBNER ET AL. (2020) present relate to this issue. To be able to integrate and harvest trees in agricultural systems, they had to be separately registered as fields of permanent crops. For this, the plot had to have a min. size of 0.3 ha. HÜBNER ET AL. (2020) suggest lowering this number to make it easier for this workaround (i.e. the separate registration of the tree rows as permanent crops) to be used.

Other suggestion by the authors relate to the length of the min. rotation length of SRC plantations. These systems had to be harvested at least once every 20 years in order to be classified as SRC and thereby an agricultural system eligible for direct payments (BMEL, 2024). Many of the modern AF systems in Germany use rows of fast-growing trees, which can be registered as SRC, if the tree rows meet the min. size of 0.3 ha. The restriction on the rotation length does not allow for the combination of e.g. short, medium, and long rotations, in which also trees for timber could be integrated into the system. For this workaround to be an effective tool to implement diverse and multifunctional AF system, this restriction would have to be removed. However, institutional barriers to workarounds, which only must be used because AF itself is not recognised as a formal land use unit, can be considered obsolete. This is because in 2023 AF has been officially defined and is now recognised as a formal agricultural land use type. Only in organic agriculture, where no annual support for the management of AF system exists in the form of ES 3, these workarounds remain of high interest. This is especially because permanent crops under organic cultivation are funded with up to 1,450 €/ha/a (BMEL, 2024).

2.4.2. Restrictions for tree plantings

The second category in which 3 of the 20 barriers presented by HÜBNER ET AL. (2020) can be summarised does not affect solely AF but tree plantings in general. The planting of trees in riparian zones, in areas designated as flood prone, as well as in permanent pastures did require a special permission. Planting trees in permanent pasture was considered, a conversion of pasture into permanent crops, especially if trees were to be planted in larger strips and harvested for their biomass, since this was only possible when registering this area as SRC. This conversion of permanent pasture could either be entirely prohibited or required the conversion of another land use type such as arable land into permanent pasture. Since 2023 the AF definition in § 4, GAPDZV does explicitly state, that the establishment of single trees as well as tree rows on permanent pasture is allowed for the conversion of pasture to AF.

Germanys Water Resources Act (WHG[15]) states that native trees and shrubs must not be removed from riparian areas, except for when done as part of appropriate forestry. Non-native woody species must also not be planted in these areas. This prohibits the potential establishment of AF systems along running water bodies, although this could potentially benefit the aquatic ecology through protection from agro-chemical drift-off. The requirements for AF systems of ES 3 states, that the wooded area of AF systems must maintain min. 20 m from the field edge. However, alongside water bodies, this distance may be reduced. The precise distancing requirements are not specified in the GAPDZV, which might make a consultation of the responsible authorities necessary to ensure the legal harvest of trees from the AF system.

[15]Water Resources Act (WHG) of July 31, 2009 (Federal Law Gazette. I p. 2585), last amended by Article 7 of the Law of December 22, 2023 (Federal Law Gazette. 2023 I No. 409).

It is however questionable, if a vague phrase like the one in the GAPDZV might counteract the restrictions laid down in the WHG.

2.4.3. Ecological potential of AF is disregarded, therefore not renumerated.

HÜBNER ET AL. (2020) criticise the disregard of AF as a land use method to counteract a multitude of ecological problems. Six of the 20 barriers presented, can be assigned to this category. AF systems were not accepted as a method for the reduction of erosion on agricultural fields, not considered as ecological priority areas, could not be used as a production integrated compensatory measure, and were absent from the GAK, the renewable energy law as well as spatial planning programmes.

The new CAP reform addressed many of these issues. AF is now explicitly mentioned as a measure for the reduction of erosion. Their establishment on agricultural fields labelled as at risk for erosion, can mean regaining certain privileges that are lost when a field is categorised as at risk, e.g. ploughing in certain periods of the year (BMEL, 2024, p. 509).

As part of the Greening requirements of the old CAP, a certain percentage of arable land had to be registered as ecological priority areas. Landscape features and even SRC plantations were possible areas to be registered as EPAs. AF systems were not explicitly mentioned as EPAs, since no legal definition had been established yet. The latest CAP reform removed the Greening requirements as such which are now integrated in the extended conditionality. A mandatory maintenance of 7 % of "unproductive land" replaced the EPAs. AF is explicitly not regarded as such, since it is a productive, agricultural system (WEINGARTEN & RUDLOFF, 2020).

Contrary to what HÜBNER ET AL. (2020) found, AF systems have been used as production-integrated compensatory measures before. The Federal Nature Conservation Act (BNatSchG[16]) states in § 13 (et seq.), that unavoidable interventions in nature must be compensated. The production-integrated compensation of interventions in nature are not a subsidy measure and are therefore independent of subsidy policies and CAP reforms. Farmers can implement these compensatory measures either for third parties or for their own interventions (building of a barn). The area remains under agricultural management and is therefore still eligible for direct payments (BÄRWOLFF, 2014). HÜBNER ET AL. (2020) state, that AF systems should be considered compensatory measures, as are e.g. traditional meadow orchards. In 2017, the planting of an AF system with high value timber trees on extensively managed grassland was indeed recognised as a production-integrated compensatory measure in Thuringia (see: LANDESHAUPTSTADT ERFURT, STADTVERWALTUNG, 2017). However,

[16]The Federal Nature Conservation Act (BNatSchG) of July 29, 2009 (Federal Law Gazette I p. 2542), last amended by Article 3 of the Law of December 8, 2022 (Federal Law Gazette I p. 2240).

recognition as a production-integrated compensatory measure is always at the discretion of the responsible administration and must be reviewed on a case-by-case basis.

The latest CAP reform also brought the inclusion of AF into the GAK. The Länder are therefore encouraged to fund the establishment of AF systems through Pillar II funds, along with co-financing from the Bund. This plus all the arguments above show, that the ecological potential of AF is starting to be recognised by German authorities. The present funding options as well as their adequacy are, however, up for debate and are discussed in this thesis.

2.4.4. Institutional barriers to the adoption of AF in Germany after 2023

With the inclusion of AF into German funding legislation, many of the institutional barriers, which were present before 2023 got obsolete. This is because they mostly referred to the lack of officially registering agricultural plots as AF system and the resulting workarounds German AF-pioneers had to go for to make use of the benefits of trees in agriculture. As it is to be expected with rules and regulations, their introduction does not solely lead to legal clarity but also to restrictions, which those affected by them can perceive as obstacles. These obstacles are in conclusion:

- Insufficient funding.

Although increased vom 60 to 200 €/ha of wooded area in 2024, the funding is still regarded as insufficient (BÖHM, 2023). Funding should, to a certain degree, offset establishment cost, higher management cost and reimburse farmers for the provision of ESS and internalisation of externalities associated with regular intensive farming. It is therefore necessary to not only subsidise the maintenance of AF systems with an adequate amount but also their establishment, since investment costs can be large. As presented in section 2.3.2.1., investment support measures have been implemented in certain funding regions of Germany. Their adequacy, as well as their popularity with farmers, must be considered uncertain.

- Lack of (subsidised) consulting.

Making long term decisions such as investing in perennial elements demands a thorough planning process, which considers many aspects of not only current but also possible future conditions. This includes uncertainties regarding a change of climate and in demand for as well as price of certain products. A comprehensive analysis of biophysical site conditions, market availabilities, possible value chain creation, personal goals and aspirations of the farmer, an assessment of the legal framework considering possible restrictions and many things more. This process needs to be supported professionally by specialist consultants (HERNÁNDEZ-MORCILLO ET AL., 2018). A number of private consultants are offering their services in Germany, e.g. “Baumfeldwirtschaft – Deutsche Agroforst GmbH, https://baumfeldwirtschaft.de/", "TRIEBWERK - Regenerative Land- und Agroforstwirtschaft UG, https://www.triebwerk-landwirtschaft.de/", " WALD21 GmbH, https://wald21.com/".

Prices can range from 1,500–6,500 € per AF project, depending on the previous knowledge of the farmer (B. Kayser, personal communication, 28. February 2024). Additional hours invested by the farmer to participate in the process can be expected, leading to even higher expenses. This crucial step in the establishment of AF systems must not be neglected and must be recognised by the responsible authorities as one of the core funding targets. Certain German funding regions do subsidise consulting, ranging from 1,500–6,000 €. Conversely, Lower Saxony explicitly excludes planning/consulting from its investment support scheme. To reach national AF goals, planning/consulting must be funded nationwide to provide an optimal basis for AF systems to create showpieces which incite replication.

- AF definition is too restrictive.

While before the registration of AF systems as such was not possible due to nonexistence of a fitting formal land use unit, the introduced definition allows only for the registration of specific types of AF systems. Especially the extended requirements for AF systems eligible for ES 3 funding have been criticised as being too restrictive (e.g.: ZEHLIUS-ECKERT & BÖHM, 2022; BÖHM ET AL., 2023). Ruling out the option of establishing tree rows on the edges of fields entirely is seen as an unnecessary restriction, which does not allow for the necessary flexibility in planning functional AF systems. The distancing requirement of 20 m to the field edge must therefore be entirely removed, as is the min. required width of the tree rows of 3 m. Additionally, the min. distance between tree rows is to be lowered to 10 m (BÖHM ET AL., 2023).

- Excessive bureaucracy.

Registering a plot as AF while complying with the requirements mentioned in § 4 or Attachment 5, 3. GAPDZV (ES 3), is considered a bureaucratic burden for farmers, since a unique condition is included within the process. Farmers must get the approval of a competent authority on a management concept, which includes:

- field measurements,
- information about the type of woody plant (tree or shrub),
- the species included in the system,
- their estimated share within the tree row (or number of trees in scattered tree systems),
- their purpose of use,
- harvesting interval,
- estimated first harvest,
- a sketch of the system.

Since no other agricultural land use types nor ES requires such provision of a management concept, it is considered to be discouraging to farmers, essentially having the opposite effect of what a subsidy is supposed to bring. The legal framework should be designed in such a way that farmers are encouraged and supported in implementing AF (Böhm et al., 2023).

- No explicit inclusion of AF in the nature conservation legislation.

The definition and inclusion of AF in national funding legislation aims to create legal certainty. However, AF stakeholders consider this legal certainty not fully realised if future conflicts between agriculture and nature conservation are not counteracted in advance. A "harmonisation" of funding legislation and nature conservation law is demanded. This is supposed to ensure that AF systems remain undoubtedly agricultural systems, even if they take on the character of protected habitat. The complexity and diversity of AF systems do not always make it possible to immediately recognise their primary purpose of sustainable production. This is why BÖHM & ZEHLIUS-ECKERT (2023) pledge for the integration of the term "Agroforstwirtschaft" or "Agroforstsystem" (German for agroforestry (-system)) into following sections of the BNatSchG).

- § 30 BNatSchG deals with habitat types protected by law. Their destruction or impairment is prohibited. Traditional meadow orchards are listed here as protected habitats (§ 30, (2), 7.). Silvopastoral AF systems with fruit trees could therefore be regarded as protected habitat. The authors see this as a potential for future conflict, when farmers decide to make changes to their AF system, reacting to economic or even biophysical changes. Such changes could include removing single trees, changing the species composition, or removing the system all together.
- § 39 BNatSchG deals with the general protection of wild animals and plants. It is e.g. prohibited to remove wild plants from their location without "reasonable cause" § 39, (1), 2. BNatSchG). It also states that it is prohibited to cut, coppice, or remove trees outside of forests, SRC plantations, hedges, living fences, bushes, and other wooded structures in the period from 01.03.–30.09., while only gentle shaping and maintenance to promote the health of trees is permitted. BÖHM & ZEHLIUS-ECKERT (2023) suggest adding AF into the catalogue of exceptions.
- § 40 BNatSchG deals with the release or introduction of plants and animals into habitat. The introduction of plant species that are not native to an area or haven't been present in the wild for over a century, requires authorization from the competent authority. Agricultural systems however are explicitly exempt from this rule (§ 40, (1), 1.). BÖHM & ZEHLIUS-ECKERT (2023) nonetheless pledge for at least an explicit communication of the fact, that AF systems are agricultural systems to the regional (higher) and local

(lower) nature conservation agencies. This is supposed to prevent unnecessary lengthening of the bureaucratic process associated with establishing AF systems.

- Tree protection in rural landscapes is often regulated on federal state level and can e.g. determine which tree species of which age and/or dimension are allowed to remove. BÖHM & ZEHLIUS-ECKERT (2023) suggest adding AF to the list of exceptions within the federal state legislations to guarantee that trees planted for the purpose of timber production in AF systems are allowed for harvest, no matter their age/dimensions.

In some circumstances, the only thing that distinguishes certain types of AF systems from certain landscape features/habitat types protected by the BNatSchG is their agricultural status. For this, they must at least fulfil the requirements of § 4 GAPDZV and be registered as an AF system. The definition of AF and the associated requirements are stated in a regulation, which fundamentally are situated below laws/acts in the hierarchy of norms. This is because laws/acts are enacted by the legislative powers (in Germany: The Bundestag), while regulations are issued by the executive power (e.g. a ministry) only based on an authorisation granted by a formal law (BMG, 2016). It is conceivable that in the event of a legal dispute, the BNatSchG would be attributed more importance than the GAPDZV if the AF system in question were to assume the character of a protected biotope. Yet, no specific AF-related example could be found. However, in this context, it is worth mentioning that traditional meadows orchards, for example, have only been legally protected biotopes under the BNatSchG since March 2022 (LUKAS & SCHRÖTER, 2022). This shows, that even laws/acts are not set in stone and are subject to change, adapting to and reflecting a changing political and societal environment. Moreover, in the GAPDZV itself it is stated in § 1, that “the regulations of this ordinance apply to the implementation of the GAP Direct Payments Act (GAPDZG[17]) and the Union regulations mentioned in § 1 of the GAP Direct Payments Act.”. It can therefore be argued that the definition of AF systems as agricultural systems in the GAPDZV cannot automatically be transferred to the BNatSchG. It must be assumed that the term "agricultural land" is therefore understood independently in the BNatSchG. Real legal certainty can therefore only be achieved by including explicit exceptions for AF in the BNatSchG, as demanded by the DeFAF.

2.5. Decision analysis in agriculture

Agricultural systems are man-made systems with the primary goal of meeting human needs; thus, they cannot be regarded as solely biophysical. Instead, their integration into socio-economic conditions, shaping human and, therefore, global realities must be recognised. Agricultural systems exhibit a characteristic where their dimensions depend on the observer’s perspective and the specific question used to analyse them. The scope of perception can reach beyond the biophysical processes which comprise crops, livestock and their interaction with

[17]GAP Direct Payments Act of July 16, 2021 (Federal Law Gazette I, p. 3003; 2022 I, p. 22)

the soil, the atmosphere, and their surrounding landscape. This is especially true when decisions are made, which affect these inherently complex systems. LUEDELING & SHEPHERD (2016), argue that decision-makers rarely consider the multitude of functions and trade-offs connected to agricultural production, be they farmers or politicians.

Since agricultural decisions are always made under uncertainty, methods to support such decisions must acknowledge and deal with the inherent limitation on information about the system in question. DA, which can be described as the application of decision theory principles to real-life decision situations, offers support in such circumstances (EIDSVIK ET AL., 2015). DA is used to reduce the uncertainty of a decision-making process by providing insights into trade-offs between options. Providing an objective informative basis, reduces the impact of cognitive biases or “wishful thinking” on the choice to make (WHITNEY ET AL., 2018).

LUEDELING & SHEPHERD (2016) highlight 6 key principles of the DA approach. The first principle is, to focus on a decision. In agricultural sciences, DA can streamline research into focusing on decision-relevant factors instead of dedicating time and resources into generating knowledge about details, which might be unnecessary in the decision-making context. Relevant to the decision are the system components which are altered by choosing a specific option, typically expenses related to investments or management changes and benefits created by the intervention. Benefits and cost do not have to be solely monetary in nature. Socio-ecological impacts of agricultural system changes can be of high importance to the decision maker and can therefore be included into the analysis process.

The second principle is to use the current state of knowledge, when analysing decisions. Making changes to agricultural systems, e.g. adding new annual crops to the rotation or planting trees and shrubs, can have different impacts on the operation, depending on e.g. site conditions, market access or resource availability. A precise prediction of intervention outcomes is thereby highly unlikely but may also be unnecessary in the context of decision-making. Gathering vast amounts of data for the site of the agricultural system in question can be impractical and, in many cases, unfeasible. Considering insights found in literature, experiences made by local agriculturalists as well as estimations made by experts can therefore be an appropriate starting point for the system analysis. In fact, the integration of experts, stakeholders and decision makers is another DA principle highlighted by LUEDELING & SHEPHERD (2016). To ensure that all relevant aspects of a decision are covered, it is often advisable to collate the subjective opinions of many experts to create a more objective picture. Participatory processes such as workshops are one method to collect this information. What results from this approach is a rough understanding of the most essential processes and aspects of the decision, which is captured first qualitatively in a conceptual model and then quantitatively in a mathematical model (KEENEY, 1982; LUEDELING & SHEPHERD, 2016).

Taking as many information resources as necessary into consideration, to inform a decision, inevitably leads to the remanence of uncertainty. Crop yield studies may provide different results based on site conditions; experts may have different opinions based on their previous experiences. Expressing this uncertainty explicitly and quantitatively is therefore crucial to the approach and the forth DA principle highlighted by LUEDELING & SHEPHERD (2016). Experts, who know about dependencies and resulting fluctuations of values taken on by variables, can be hesitant to provide estimations. “It depends” is often the answer to a subject-specific question. It is important to use methods that enable two things: firstly, to capture a realistic values and variabilities of the system components; and secondly, to quantify the uncertainty of the expert. This is done by quantifying variables by assigning value ranges rather than fixed values or averages. The broader the value range applied to the variable, the higher the level of variability and uncertainty. Expressing one’s own uncertainty in this way is a skill, which can be taught in so called calibration trainings (HUBBARD & SEIERSEN, 2016). The process includes an introduction to concepts such as cognitive biases, confidence intervals and the information contained within probability distributions. The training consists of multiple rounds of random questions, that may be outside of the expert’s field, which are to be answered by providing a lower and an upper value. The task is to select the value ranges in such a way that the correct answer lies within the specified range in 90 % of the cases. The more unspecific the question is or the more uncertain the expert is, the larger the range of values must be chosen to ensure that the correct answer lies within the given range 90 % of the time. After every round the answers are evaluated, and the results presented to the experts. Additionally, methods for improving accuracy when making estimations are offered. Upon achieving a consistent success rate of 90 %, the experts are considered calibrated (HUBBARD, 2014).

The experts are then asked to quantify the variables of the before constructed conceptual model. Calibration increases the probability of integrating only plausible value ranges into the mathematical model. This model is then used to make probabilistic predictions of decision-outcomes. One method of producing probabilistic predictions is the Monte Carlo simulation. This approach consists of running the simulation several thousand times (usually at least 1,000 times), assuming a different randomly generated value for each variable in each run. These randomly generated values are always within the value ranges assigned to the variables. However, not every value within the ranges is assigned the same probability of occurrence. Rather this is based on the additionally specified probability distribution. This means that values around the specified or calculated median of the input factor are most frequently included in the simulations (when assuming e.g. a normal distribution for the variable) (WACHHOLZ & MALZEW, 2024). The result of the Monte Carlo simulation is a probability distribution of the output variable of interest. It does not only provide a plausible range for the decision-outcome but informs also about the likelihood of occurrence of certain outcomes as well as the overall uncertainty associated with the decision outcome. Large outcome distributions indicate higher variability and therefore a higher uncertainty.

If the informative value of the simulation outcome remains too low, an analysis of the impacts of certain input variables on the output variable provides insight into which uncertainties to target through additional research. This analysis is called Value of Information (VoI) analysis. It is based on statistical sensitivity analysis, which examines, how changes in a model's parameters, affect its results (CASWELL, 2019). This indicates that not all uncertainties are of equal importance to the decision. This highlights, that a resource-intensive research project, focusing on generating observational data, is not always the appropriate method. That is especially true, if the priority is to support a real-life decision that needs to be made promptly and will be carried out with or without scientific support (HUBBARD, 2014). Based on the VoI, further analyses can be carried out, such as the calculation of the Expected Value of Perfect Information (EVPI) It expresses, often monetarily, which amount of resources a rational decision maker should allocate to the elimination of uncertainty associated with a specific input variable (HUBBARD, 2014). Using the VoI to prioritize decision-specific research is another key principle of DA (LUEDELING & SHEPHERD, 2016).

Lastly, LUEDELING & SHEPHERD (2016) argue that the described methodology offers the opportunity to model systems, more holistically than deterministic methods permit. As described above, decision-making can extend beyond monetary changes alone. Positive ecological influences, such as habitat creation, or social factors, such the enhancement of landscape aesthetics, may result from, e.g., the establishment of AF systems. These factors can influence the decision for or against a targeted subsidy and should be included and quantified in the decision-making process. Although it is hard to exactly capture the quantitative changes in e.g. "habitat value" or "landscape aesthetics", HUBBARD (2014) argues, that everything, which affects system performance must be measurable, meaning, the uncertainty associated with the effect can be reduced by gathering information about it. Even if no "hard data" is available for a factor which has been pointed out as decision-relevant, it should be included in the model. Disregarding a factor completely because of a high uncertainty associated with it implies that it is not worth including at all (WHITNEY ET AL., 2018).

3. Materials and Methods

The aim is to assess the effectiveness of the funding measures outlined in section 2.3. in incentivising farmers to adopt AF systems. For this, an existing AF system is modelled and used as the basis for further investigations. The upcoming sections will cover the biophysical conditions of the study site, the farmers' motivation for implementing the system, and provide a detailed description of the AF system itself. Then, a description of the methodology is provided, which was used to model the AF system conceptually and mathematically and to analyse the resulting model output.

3.1. Case Study – Silvoarable Agroforestry System Steinfurt

3.1.1. The study site

The AF system modelled in this thesis, is located in the district of Steinfurt in North Rhine-Westphalia (NRW), Germany. Steinfurt is in the Westphalian Bay ("Westphälische Bucht"), situated at an average elevation of 60 m above sea level. From 1990–2020 the area experienced a mild oceanic climate with an average temperature of 10.2 °C, the coldest month being January (2.6 °C) and the warmest month being July (18.5 °C). In the same period, Steinfurt received an annual mean precipitation of 783 mm. Monthly average rainfall ranges from 42 mm in April to 78 mm in July and August with a standard deviation of 10.5 mm, indicating an even distribution of annual precipitation (KLIMAATLAS NRW, 2024). The area is generally characterized by agricultural production (63 % of total area) with 80 % of agricultural land being arable land (IT.NRW, 2018).

3.1.2. The farmer's motivation

The intensive land use noted at the study site area motivated the farmer, Jan Große-Kleimann, to adopt an AF system to modify his agricultural practices. He is self-reportedly committed to enhancing the soil fertility of the agricultural land he took over and is now managing. His strategy involves implementing "regenerative" practices such as no-till direct seeding to minimise soil disturbance, cover cropping, using compost extracts for vitalization of the arable crop, and microscopy as a tool for monitoring the soil-microbiology.

The AF system is yet another corner stone of his plan to address the farm's long-term sustainability. The farmer has opted for an AF system to minimise wind erosion to sustain or enhance soil fertility, proportionally increase his production of crops for human consumption, and engage in public outreach. Through his communication efforts, he wants to emphasize the benefits of regenerative land use practices, advocating for a heightened understanding and appreciation of farming in general and his products. The establishment of the AF system was done through public engagement. By organising a community-based initiative, volunteers assisted in tree planting for the AF system. Over 60 individuals participated in the initial planting campaign in 2022. Leveraging this opportunity, the farmer informed participants about his vision for sustainable land use and the considerable potential he identifies in AF. His motivations stem from his conviction, that the transformation of agriculture towards a socio-ecologically sustainable land use system partly depends on well-informed consumers (J. Grosse-Kleimann, personal communication, 23. January 2024).

3.1.3. The Agroforestry system

All of the information below was gathered in an interview conducted in January 2024 (J. Grosse-Kleimann, personal communication, 23. January 2024). The farmer established a silvoarable alley cropping system with rows of apple trees for table apple production (Fig. 1). It was established in 2022 over 10.14 ha with a wooded area of 0.57 ha or 5.6 %. The tree rows are 3 m wide and between 60–180 m long, adding up to 1,890 m length. The AF plot has the typical geomorphological and pedo-climatic conditions of the respective geographical region with the field being level with no noticeable inclination. The soil is classified as a loamy sand with a soil rating of 35–50 points (Bodenpunkte). The AF system's 15 tree rows are placed in a north to south facing direction perpendicular to the main wind direction. This placement was chosen to minimise light competition between the arable crops and the apple trees while maximising wind speed reduction.

The tree rows contain a total of 473 trees of 9 different apple cultivars. The varieties were chosen carefully to be suited to the intended extensive cultivation of apples with minimal chemical inputs. No fungicides, herbicides or insecticides are to be used on the trees. Plant protection measures are limited to using pheromone dispensers for codling moth (*Cydia pomonella*) control. This insect pest management is supposed to ensure an improvement of biological diversity and the establishment of beneficial insect populations, to provide pest regulation services within the arable crop between tree rows. Both the rootstocks and the trunk-forming component of the trees were carefully selected. The rootstocks were chosen to be moderately (cultivars M4, MM106) to vigorously (cultivar M25) growing, to handle the comparatively low soil quality and competition from arable crops. The trunk-forming variety grafted in between the rootstock and the fruit bearing cultivar, is the "Seestermüher Zitronenapfel", chosen for its reported low tendency of alternate fruit bearing, in hopes of passing on this property onto the fruit bearing cultivar. The trees have a short trunk of only 60–80 cm thus being considered bush trees, which will reach a max. height of 3–5 m. Depending on the cultivar, the trees are spaced between 3.5–5 m apart within the row. The mature system (9–12 years old) will consist of nearly closed rows of apple trees with wide, low canopies, which will give the tree rows a hedge-like appearance.

The preparation of the tree rows consisted of loosening the soil, using a deep harrow and a subsequent superficial cultivation, using a rotary hoe. This preparation enables deep rooting of the apple trees and prepares the rows for seeding of a cover crop to suppress weeds. While the planting holes were dug out using a small excavator, the trees were prepared and planted manually. The tree's roots were equipped with a vole mesh to protect them from damage during the years of establishment. Additionally, a protective mesh against deer browsing was installed. Furthermore, a drip irrigation system was installed in the tree rows to maintain an adequate water supply.

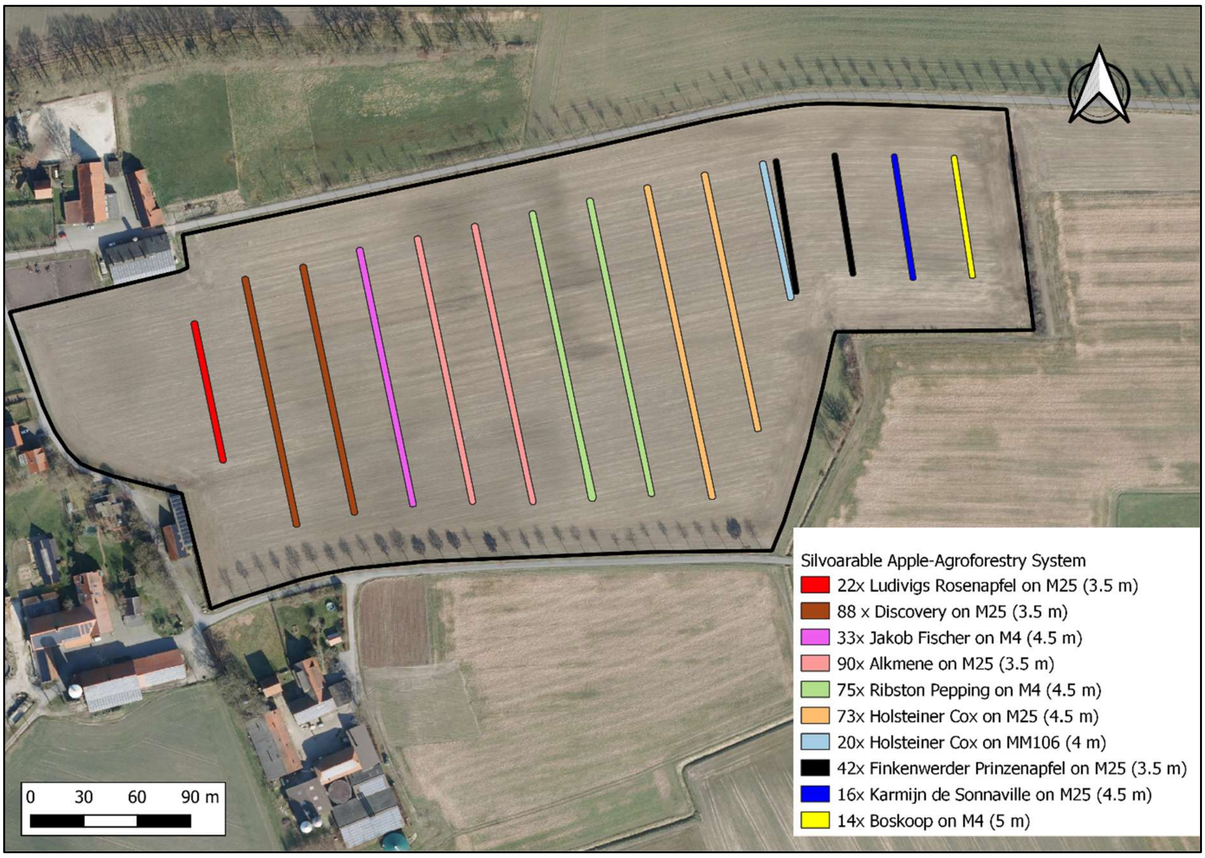

Figure 2: Aerial view of the silvoarable agroforestry system in Steinfurt.

The arable component of the system is under conventional management, synthetic pesticides and fertilizers are used. It is cultivated with a crop rotation of maize, winter wheat, winter barley and rape seed and serves the main purpose of delivering fodder for the pig fattening operation which is the main business of the farms. Soil cultivation is minimized strategically and where possible, no-till methods with the application of a total herbicide, are used to prepare the field for sowing.

This thesis considers using a simplified version of the information described above to develop a DA model (explained in the following section).

3.2. Creating the decision model

A DA (Luedeling & Shepherd, 2016) approach is used to model the above described AF system to:

a) provide information, on the impact of the decision to implement said system, focusing on the systems profitability indicated by the NPV,
b) identify decision-relevant uncertainties and the value of their reduction,
c) assess how different funding schemes affect the NPV of the system. Offer decision support to policy makers responsible for the development of AF support measures.

To achieve this, the workflow as describes in Fig. 2 is adopted from DO ET AL. (2020). A detailed explanation of each step is provided in the following sections. The overview of the workflow includes developing a conceptual model of the AF system. To understand the impact pathways of the adoption of AF systems, a literature review, expert consultation, and the identification of decision-relevant factors were carried out. The resulting impact pathway provides an overview over the identified relevant input variables and their impact on the output variable, namely the NPV of the decision.

Subsequently, value ranges and probability distributions are assigned to the input variables and the conceptual model is transcribed into a probabilistic one. This is done using the available information while explicitly depicting uncertainty quantitatively. Monte Carlo simulations are employed to generate output distributions, which inform the analyst about the potential decision outcome. Further analyses are conducted, to gain information on which input variables best explain variation in the output variable and which uncertainties must be reduced using additional resources.

The model is then used to test the decision across different scenarios. By integrating the funding scenarios described in 2.3.2., the impact of the support measures on system profitability is examined. The results are then used to discuss policy recommendations to create an enabling environment for AF establishment in Germany.

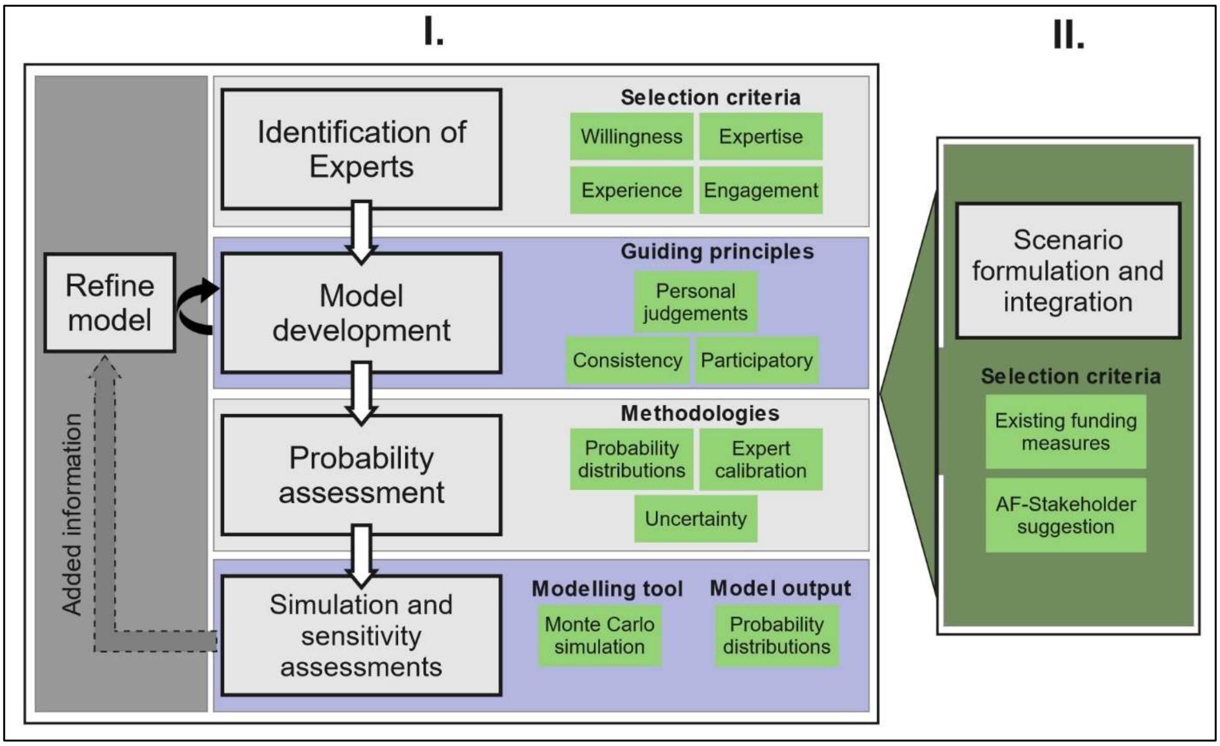

Figure 3: Workflow adopted from (DO ET AL., 2020). I. *Shows the principal stages of the decision analysis approach used to develop the AF model.* II. *Depicts the subsequent development and integration of various funding scenarios into the model.*

3.2.1. Conceptualising the decision

The first step is the identification of all decision-relevant factors, without getting lost in details about occurring processes, which do not significantly influence the decision itself. This acts as the basis of the decision analysis procedure since it provides the crucial overview over all variables, which are later integrated into the probabilistic model (LUEDELING & SHEPHERD, 2016). For this, all available information was considered, which includes expert estimations. In a participative process, the expert knowledge was collated. This was done to capture different perspectives that complement the experience and level of knowledge of the decision analyst. Experts on arable crop management, extensive apple production and fruit tree pruning, agricultural investment economics, irrigation systems and AF were consulted in addition to the farmer. Important selection criteria were the level of expertise as well as the assumed motivation in the advancement of AF and AF-related scientific knowledge generation. The complete list of experts consulted can be found in Annex V. The expert interviews, to gather information on the system and the decision, were held in one-on-one sessions. The experts were provided with brief information about the farm and then were consulted on decision-relevant aspects which ought to be included in the model. The information gathered in the expert interviews was analysed alongside information from the literature review to construct the conceptual model.

The main aim of this thesis is not to depict the examined AF system as holistically as possible but rather to use it as a basis for the comparison of different funding scenarios. Economic variables such as costs and monetary benefits have therefore been the focus of the modelling process. Costs are categorised into investment costs, running costs, and those with a probability of occurrence greater than 0 but without regularity. Benefits are categorised into the yield from the arable field and the yield generated by the tree rows, i.e. the tree yield and potential AF specific subsidies. Risk events, like damaging weather events, are also considered important. Additional modulating factors, such as the discount rate are also considered and included into the model.

3.2.2. Quantifying decision-relevant variables

The conceptual model is converted into a probabilistic one by using simple mathematical formulations to represent the relationship between the variables and ultimately their influence on the outcome variable. The input variables are assigned value ranges as well as probability distributions. The ranges define the 90 % confidence interval, meaning that the specified values encompass the truth in 90 % of cases. The distributions offer insight into the probability of the variable to take on specific values. This thesis only assumes positive-normal or constant distributions for the input variables.

The source of the value ranges, which quantify the qualitative information, is again all available knowledge. This means, that also the quantitative information has not been derived by reviewing literature and having experts make estimations based on their rich experience.

While expert interviews are a valuable tool to obtain information when data is scarce, the DA procedure outlined by HUBBARD (2014), includes the crucial step of expert calibration. This step requires that the consulted experts are willing to invest a significant amount of time into the calibration process. The calibration training alone can take several hours, depending on the ability of the experts to understand and internalise the taught methods as well as the teaching abilities of the analyst. While this willingness to participate may be high in situations where experts are simultaneously stakeholders in the decision and have a high interest in the analysis of it, this is not always the case. For the reason of low willingness to participate in all other interviewees, only one expert consulted for this thesis has been fully calibrated, namely AF expert and consultant Burkhard Kayser. The other experts' estimations were therefore only included into the model after a process of verification by consulting other sources such as the available literature.

After assigning values and probability distributions to all decision-relevant variables, their relations and ultimately their impact on the output variable, are established via mathematical equations. This transcription of the conceptual model into a mathematical model allows for the analysis of the decision via probabilistic simulations. The code is written in the R programming language (R CORE TEAM, 2023), using functions from the decisionSupport-package (LUEDELING ET AL., 2023). Most variables are transcribed into simple mathematical equation using simple summation and multiplication. For example, the total cost associated with planting the trees [€] when establishing the AF system in the first year, is the sum of all costs of the tasks involved in planting. These costs [€] are, in turn, the product of the expected working hours required to complete the task [h] and the expected costs per working hour [€/h].

Less trivial relationships or processes were described using functions from the decisionSupport-package. These relationships include, e.g., the behaviour of apple yields over time. It is assumed, that fruit tree yields can be modelled using the Gompertz curve (LUEDELING ET AL., 2023), a sigmoidal or S-shaped function (Fig. 3). It expresses slow growth at the beginning, rapid growth in the middle and then levels off as it approaches the upper asymptote.

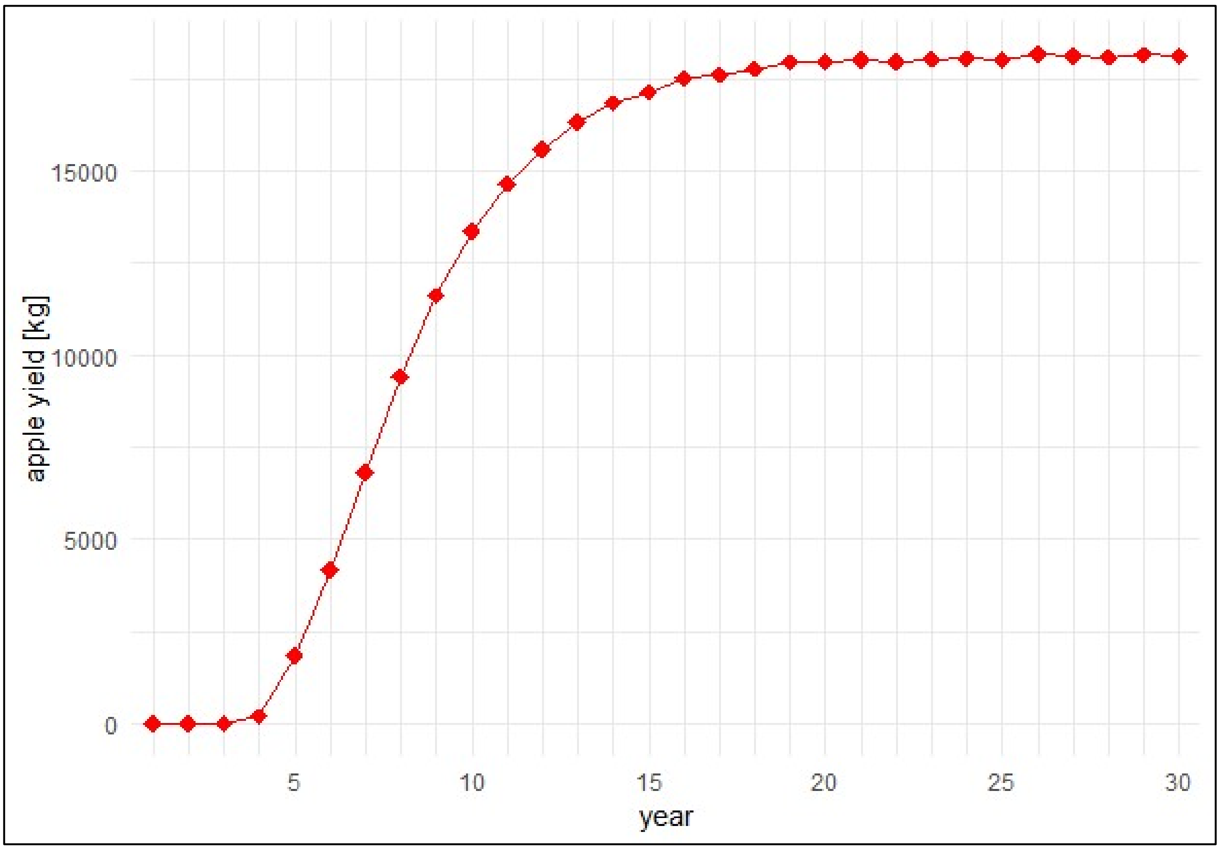

Figure 4: Simulated total apple yield generated by the AF system [median in kg]. The curve, generated with the gompertz_yield()-function from the decisionSupport-package shows the sigmoidal shape of the Gompertz function, used to model the yield development of the apple trees.

Apple yields are assumed to begin a certain number of years into the simulation, then increase over the years until the tree reaches its max. size. From this year on, apple yields are assumed to stay constant, expressing only a yearly variation around the median (i.e., no further trend towards higher or lower median yields).

Yields of the arable crops are assumed to not express any trend over the length of the simulation and only present annual variation as a deviation from a set, calculated median. To include deviations from the median greater than the set coefficient of variation, e.g. in years of damaging weather events such as drought, chance events can be modelled. These events have a certain probability of occurrence [%] and a certain magnitude of impact on the crop yield [%]. Both factors are presented as value ranges, emphasizing the uncertainty associated with them. The value ranges assigned to the apple-yield variables are derived from expert estimations (M. Grolm, personal communication, 5. March 2024; B. Kayser, personal communication, 28. February 2024) and literature (e.g. CRAWFORD, 2015).

Input values for the arable crops, on the other hand, rely on calculations using yield data from 1999 to 2022 in the district of Steinfurt. Additionally, data from the neighbouring districts of Borken and Coesfeld, as well as the city of Münster, are considered in these calculations (LANDESDATENBANK NORDRHEIN-WESTFALEN, 2024). Using yield data from this period and projecting this data into the simulated future is assumed justifiable, because arable crops in central and northern Europe exhibited an observable stagnation of yields since the 1990s. This is primarily due to the high land efficiency of intensive agriculture in these regions combined with the change of the agricultural management in response to a changing CAP and climate change effects (WIESMEIER ET AL., 2015).

It is important to point out that, the model does not explicitly incorporate climate scenarios along with their respective probability of occurrence and associated effects. According to data from the "Regional Climate Atlas", a website provided by the Helmholtz Association, changes in precipitation, length of dry periods and the number of dry periods in the near future (2021–2050) are highly uncertain. The length of the longest dry period could increase by up to 11 days or decrease by up to 3 days, with a possible mean change of 0 days (REGIONALER KLIMAATLAS DEUTSCHLAND, 2023a). The number of dry days can increase by 1 or decrease by 2 days, compared to 1961–1990 (FARDA ET AL., 2010, in: REGIONALER KLIMAATLAS DEUTSCHLAND, 2023b). The yield data used in the model is data collected over a 23-year period (Fig. 4). This period includes drought-years such as 2003, 2007, 2011, 2017, 2018, 2019, 2020 and 2022 (maize data contains the period of 2005–2022) (UFZ, 2023). It can therefore be assumed, that the effect of water stress on crop yield in the regarded region is captured by the employed value ranges for the respective variables and the coefficients of variation, which are calculated based on this data. Thereby, potentially occurring weather-related effects are acknowledged and included by utilizing the probabilistic nature of the model, foregoing a detailed climate prediction for the study site, which is out of the scope of this thesis.

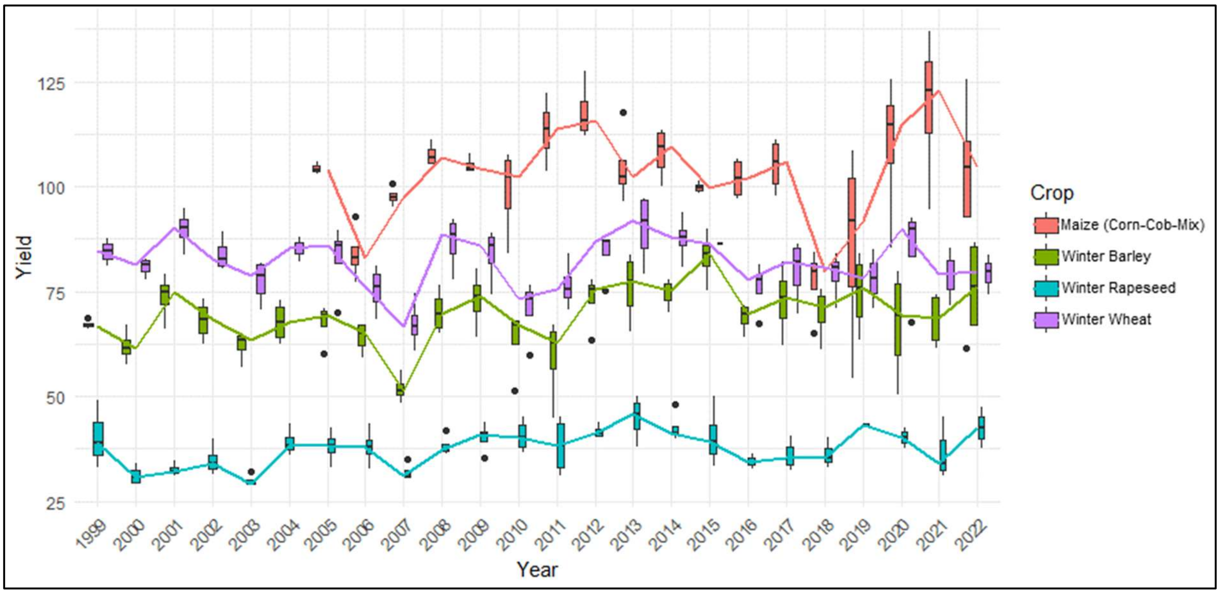

Figure 5: Barley, rapeseed and wheat yields [t/ha] from1999-2023; Maize yields [t/ha] from 2005-2022. Each boxplot represents 4 data points, 1 point each from the districts of Steinfurt, Coesfeld, Borken and Münster (LANDESDATENBANK NORDRHEIN-WESTFALEN, 2024). Each line connects the median crop yield values to visually highlight the course of the data.

3.2.3. Simulating the decision

Ultimately, all cost and benefit related variables are listed and their mathematical relations are established in from of R code. This allows for the calculation of the overall economic performance of the baseline system (i.e. the arable system) and the AF system over a 30-year period, allowing for a quantitative comparison of the systems profitability. Economic performance over a certain time is calculated by the summation of net cash flows of each time period after discounting them to calculate the current value of these future streams of income. This financial tool to evaluate the profitability of an investment over time is called the net present value, NPV (GALLO, 2014; GASPARS-WIELOCH, 2019). It provides information on the present value of a future cash flow, be it positive or negative.

$$NPV = -C_0 + \sum_{i=1}^{t} \frac{C_i}{(1+r)^i}$$

C_0 establishment cost [€]

C_i cash flow in year i [€]

r discount rate [%]

t duration of simulation [a]

By applying a designated discount rate to future cash flows, one can factor in the influence of time or opportunity cost on benefits and costs, essentially acknowledging the time value of money, i.e., that possessing money now is worth more, than receiving the same amount of money at a later point (THOMPSON & GEORGE, 2009). The methods for capturing this relative value of money to determine the value of the discount rate are divers and can lead to different outcomes. For example, the discount rate can be expressed as the subjective preference of an investor, e.g. a farmer, whether to possess money now or receive it at a later point in time. The higher the discount rate, the more impatient is the farmer or the less does the famer value future benefits and costs (WUEPPER ET AL., 2023). This time preference is often elicited experimentally (see e.g. BOUGHERARA ET AL., 2021). Reviewing 12 studies, using different experimental methods of eliciting time preference of farmers, WUEPPER ET AL. (2023) found widely heterogeneous results with time preference-based discount rates from 3.9 to as much as 45.5 %. These subjective perspectives are important to consider, when thinking about creating a supportive environment for farmers to invest in agroecological measures such as AF, which can express a slow return on investment. However, HERMANN & MUSSHOFF (2016) show, that time preferences elicited through experiments are susceptible to cognitive biases, as they found that individuals tend to report lower values for their individual time preference, when they have previously completed questionnaires containing low numbers. This suggests a notable influence of results through anchoring.

One way of increasing objectivity when determining the discount rate is to not portrait it as the price of time but rather as the price for the provision of liquidity. This is done by basing the discount rate on market interest rates. The NPV calculated by using a discount rate based on the market interest rate indicates objectively, whether it is rational to make an investment, while regarding financial market conditions (D. Hermann, personal communication, 3. March 2024). For this reason, discount rates offered by the German federal bank (DEUTSCHE BUNDESBANK, 2024) are used in this thesis to generate the value range, which is extended by values used in other AF-investment-related studies (THIESMEIER & ZANDER, 2023).

To account for the uncertainty associated with future cash flows, expenditures etc. a probabilistic approach is used to calculate the NPV via Monte Carlo simulations. Using a total of 10,000 simulation runs, the NPV of the first main decision scenario, namely the establishment of the AF system, was generated. By subtracting the net benefit of the baseline system from the net benefit of the AF system, the NPV of the decision is isolated. To maintain consistency across all modelled scenarios, the NPVs for each are derived from the same Monte Carlo simulation, holding all other variables constant (ceteris paribus) as well as maintaining the same set of generated values, using the set.seed()-function in R. Therefore, the sole differentiating factor affecting NPVs among the scenarios is the distinct funding scheme integrated into each calculation.

In addition to the NPV, which provides one value per simulation run, the length of the discounted payback periods is calculated. This metric provides information about the length of time needed to recover the cost of the investment. The payback period is calculated based on the cumulative cash flows (CCF). The CCF is calculated by summing the net cash flow of the current period and the cash flow of the previous period(s). For example, CCF of year 1 is equal to the net cash flow of year 1. CCF of year 2 is equal to the net cash flow of year 1 plus the net cash flow of year 2 and so on. By determining, in which year the CCF turns positive, the payback period is specified. This provides another factor by which to compare decision scenarios, since shorter payback periods indicate more attractive investments. Due to the fact, that a probabilistic approach is used in this thesis and the Monte Carlo simulation creates 10,000 outputs for each year, it is inevitable, that each decision scenario will be characterised by multiple years, in which there are negative as well as positive values. This is why the year of positive CCF was determined for the 5^{th}, 25^{th}, 50^{th} (median), 75^{th} and 95^{th} percentile. This is also the standard output of the plot_cashflow()-function from the decisionSupport-package (LUEDELING ET AL., 2023).

3.2.4. Sensitivity analysis – Value of Information

The DA method provides a practical tool that can swiftly deliver simulation results to aid decision-making. However, not always are the initial Monte Carlo outputs precise enough to significantly improve the decision-making process. Decreasing the uncertainty of the output variable is possible by narrowing of the value ranges of the input variables. Given that resources such as time, finances and labour are usually constrained, efforts to mitigate uncertainty must be strategically allocated. It is therefore important to identify the variables where reducing uncertainty yields the most value. This can be done via a sensitivity analysis, which provides the information on which input variable influences the output variable the most, i.e. which sources of uncertainty contribute most to the uncertainty of the output (CASWELL, 2019).

The method used in this thesis is the Partial Least Squares regression, featured in the decisionSupport package. It was developed as the Non-Linear Iterative Partial Least Squares (NIPALS) approach and is also known as the Projection to Latent Structures regression (PLS) (WOLD, 1975). This method of sensitivity analysis is particularly useful when input variable (independent variables) are highly autocorrelated and the number of independent variables exceeds the number of observations (LUEDELING & GASSNER, 2012). The primary purpose of PLS is the prediction of the response of the dependent variable, not the explanation of the underlying relationships between variables (TOBIAS, 1996). Since for this thesis an agricultural setting is analysed, in which usually cashflows depend on the input variable of crop yield performance, which is highly dependent on a multitude of other input variables such as the fertilizer input, the pesticide application and many more, a strong autocorrelation between independent variables was assumed. Furthermore, PLS has been used as a method for determining the impact of individual variables in probabilistic models in multiple decision analysis related agricultural studies (e.g. DO ET AL., 2020; BURBANO-FIGUEROA ET AL., 2022; RUETT ET AL., 2022).

The identification of the most sensitive variables is based on the Variable Importance in the Projection (VIP) score, which quantifies the impact of individual input variables on the output variable (i.e. the NPV). VIP score equal to or greater than 1 are considered to be of significant importance (LUEDELING ET AL., 2023). The sensitivity analysis was conducted using the decisionSupport package in R.

3.2.5. Value of information analysis

After determining which input variables have the strongest impact on the model output, the question arises, how big of an investment (in terms of resource allocation) into the reduction of uncertainty can be justified. This can be answered by conducting a value of information analysis, calculating the EVPI (SZANIAWSKI, 1967). This factor assesses quantitatively the expected benefit gained from acquiring knowledge about the values of uncertain parameters within a decision model (STRONG ET AL., 2014). The inherent value of information stems from three sources, each contributing to its significance within economic frameworks (HUBBARD, 2014). Firstly, information serves to mitigate uncertainty surrounding decisions, influencing subsequent economic outcomes. Secondly, information can have an impact on human behaviour, shaping individual and collective actions, which again has a potential economic impact. Lastly, there is an intrinsic value or market value of information, in which case, information functions as a commodity, and providing it is a paid service (HUBBARD, 2014). The decision maker, i.e. the farmer, might view the value of information as its value to make better informed decisions, which otherwise could lead to negative economic outcomes. The decision analyst, assuming that the analyst's intentions are not purely altruistic, must consider all three aspects while determining the value of information.

The measurement of interest, the EVPI, is based on the concept of opportunity loss (OL), which is the cost of making a decision, which turns out to be objectively (mostly economically) the worse choice. The OL is the cost resulting in making this objectively wrong decision (e.g. an unfruitful investment) and/or the profit foregone that would have resulted from deciding for another, better, alternative. Multiplying the OL by the probability of its occurrence, results in the Expected Opportunity Loss (EOL). Generating information must result in a reduction in EOL. The difference between the EOL before and after this generation of information is termed Expected Value of Information (EVI). By reducing the value of the EOL after knowledge generation to 0, one maximises the EVI, resulting in the EVPI. Since the EVI is calculated by subtracting the EOL after additional information generation (0, when perfect) from the EOL before that generation, the EVPI is simply equal to the EOL before obtaining additional information (HUBBARD, 2014).

$$EVPI = EOL_{Before\ Info}$$

given that

$$EOL = p(wrong\ choice) \times C(wrong\ choice),$$

$$EVI = EOL_{Before\ Info} - EOL_{After\ Info}$$

and

$EOL_{After\ Info} = 0$,if information is perfect

$p()$ probability of

$C()$ cost of

The calculation of the EVPI is more complex, when working with variables, that do not have fixed values but are attributed value ranges. The above stated assumption is nonetheless valid and important to understand the concept. As stated before, this thesis uses a probabilistic approach, whereby all variables are assigned a range of values to account for the underlying uncertainty associated with them. Hence the respective integrated function of the decisionSupport package is used for the Value of Information Analysis. It approximates the EVPI numerically by using a multiple-step procedure. First, noise from the output values of the before conducted Monte Carlo simulation is reduced by smoothing it. For this a Locally Weighted Scatterplot Smoothing (LOESS or LOWESS) regression (CLEVELAND, 1979) is used. The LOESS regression determines nonlinear relationships between variables, clarifying existing nonlinear patterns within data. It works by fitting a curve to a plot of values of a variable. This is done using a multitude of weighted least square regressions, fitting regression lines to each data point, while considering only a subset of nearby points in each regression. The points in the subsets are weighted based on their distance from the initial regression line, with points closer to the regression line receiving higher weights and points farther away (i.e. points with higher residuals) receiving lower weights (CLEVELAND & LOADER, 1996; HARTMANN ET AL., 2023). The smoothed, continuous output is then multiplied by the probability density function used in the Monte Carlo simulation (i.e. an assumed normal distribution). That means, that each output value is multiplied by its probability of occurrence. The resulting values are plotted with the NPV on the y-axis and the examined input variable on the x-axis. A curve intercepting the x-axis is thereby created. The area between the curve and the x-axis is calculated and the positive and negative values are added up. The resulting value is the Expected Maximum Value (EMV) given the information which the Monte Carlo simulation was based on (i.e. imperfect information). Regarding only the positive area and ignoring the negative area provides insight into the Expected Value Given Perfect Information (EV|PI). The difference between the EV|PI and the EMV is equal to the EVPI.

$$EVPI = EV|PI - EMV$$

This metric is returned by the multi_EVPI()-function from the decisionSupport package (LUEDELING ET AL., 2023).

3.2.6. Model assumptions

Due to various reasons, certain assumptions had to be made during the modelling process. The following will present assumptions/limitations considered to be important to the thesis. The complete R-script containing the decision model as well as the entire input table containing information about all included variables and assigned value ranges and distributions can be found on GitHub, via https://github.com/SimonSwatek/Master_Thesis_DA_Apple_AF.

- Although the farmer self-reportedly plans on diversifying the crop rotation within the AF system, the crop rotation of maize, wheat, barley and rapeseed is considered for the entire simulation length in this thesis. Thereby, the effect of the main change that comes with the establishment of an AF system, namely the integration of trees into a not necessarily changing arable system, is highlighted.

- While socio-ecological benefits of the agroecological intervention are acknowledged and should be considered in assessing AF systems' pros and cons, for the purpose of this thesis, it is assumed that both the farmer and the hypothetical policy maker recognize these socio-ecological benefits. This assumption is based on two factors. Firstly, the farmer expressed an ecological motivation in the interview, which is described above (3.1.2.). Secondly, the German CAP SP clearly outlines the target of achieving the funding of 65,000 ha of AF by 2027 (BMEL, 2023b). The required incentive for farmers to contribute to the national target, must be financial in nature, and its magnitude must be determined, thereby a focus on economic variables is justified.
- By focusing on variables directly impacting the economic performance of the system, several effects resulting from interaction between the components of the AF system were ignored. Positive as well as negative microclimatic effects by the presence of the trees were not considered in the mathematical model. The potential increase in biological pest control was not further examined. Interspecific competition between the trees and the arable crop were not included in the model. This is because of time limitations and because of the thorough establishment and management plan, which is supposed to minimize competition (J. Grosse-Kleimann, personal communication, 23. January 2024).
- Choosing not to integrate microclimatic effects into the mathematical model prevents the detection of possible yield-stabilising effects of the integration of trees into arable agriculture.
- Risks which are specific to the apple tree management such as the mismanagement of the trees by the farmer were not included into the model. Faulty pruning could lead to reduced yields or alternate bearing which would have to be counteracted by additional pruning effort in the following years. It is assumed that the chance for management errors is eliminated by training at least one employee. Training costs have been included into the model.
- The AF system comprises 9 different apple varieties, with at least one cultivar (Boskoop) being characterised by high yield fluctuations (M. Grolm, personal communication, 5. März 2024). However, even yield characteristics were assumed all 473 apple trees. A comparably large value range was used for the apple yield variable also for that reason.
- Importantly, it was assumed, that 100 % of the picked apple yield is sold every year. This might not be the case. A certain percentage of apples might get damaged during the transport to the shop or during storage.

- The calculations of the subsidies were always conducted based on the gross investment costs. However, e.g. Saxony's funding is calculated based on the net investment cost, which might lead to an overestimation of the total funding sum in the model compared to what could realistically be received.
- The effective payment time of the subsidy has not been taken into account. Saxony states, that farmers must cover the investment costs in advance, even if they are subsequently covered by the subsidy. Later payments would be discounted in the NPV calculation, which would reduce their value.
- Very indirect positive effects, which have been reported by the farmer were consciously not included in the model. Such effects include, improved marketing options for the farm since establishing the AF system. As a result, cooperations with local shops have been established, which opened the opportunity to grow different crops (e.g. rye for bread) and sell them for a better price than what could be achieved in wholesale marketing (J. Grosse-Kleimann, personal communication, 23. January 2024)

4. Results

4.1. Conceptual model

The conceptualisation of the decision problem is depicted below (Fig. 5). It provides an overview of the variables included in the probabilistic model.

After reviewing gathered assessments and the statements of the consulted experts, three distinct types of costs have been delineated, situated within the left half of the figure. Investment costs include only costs associated with the AF system, since no investment into the already running arable operation is assumed. Running costs contain both, the management costs of the tree strips as well as the running cost of the arable operation. The running costs are expressed per ha to be able to capture the change in costs for the management of the arable land due to the modelled intervention. By establishing the AF system, the tree rows take up 5.6 % of the arable area, thereby reducing arable-specific inputs while adding AF-specific costs to the overall calculation. Running costs associated with the tree rows are mainly based on intensive manual labour such as pruning of the trees, mowing the tree rows etc. (see Fig. 4). Costs, which occur in one or multiple years of the simulation are associated with the AF intervention only. This section contains e.g. the irregularly occurring need for manual repair of the drip irrigation system.

The benefits, depicted as revenue and the risks which affect it, are found on the right half of the figure. The benefits relate to the potential revenue that can be generated from the sale of the both the arable crop and the apples. Annual AF subsidies as well as the AF investment support are added to this.

Weather-related risk is summarised as “apple risk” and “arable risk”. Modulating factors, which are included in the model are yield effects in the arable crop caused by the tree rows, quality class ratios, which effect the overall value of the apple yield, and the discount rate. Both the total costs and the total benefits are summarised in the target or output variable, namely the NPV.

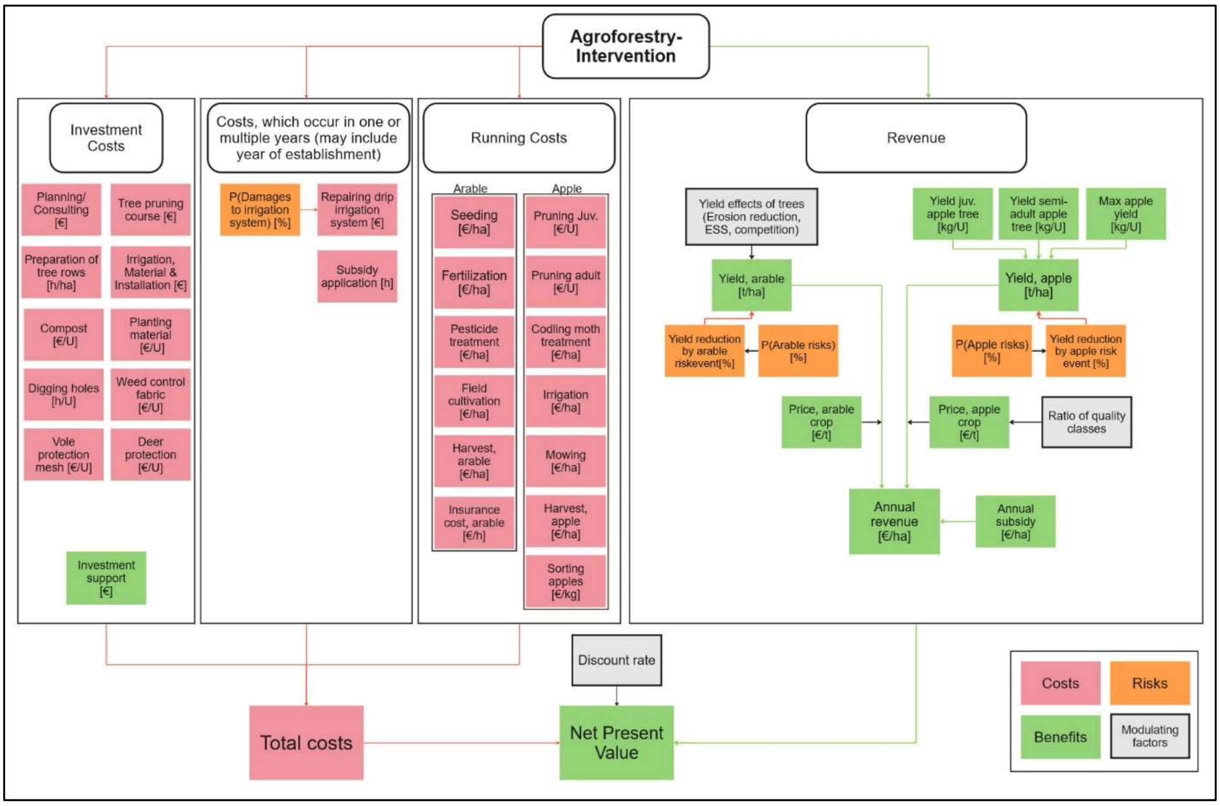

Figure 6: Conceptual model depicting variables assumed to be decision-relevant.

It is important to note, that not every variable depicted in the conceptual model could be integrated into the mathematical model, while some variables depicted in the conceptual model consist of multiple varying factors in the mathematical model. For example, the "apple risk" was not explicitly included but rather depicted by assigning a large value range to the apple yield variable. This is due to the high uncertainty of the possible occurrence of risk events damaging apple yields. The apple yield expert (uncalibrated) considered hail and late frost to be of negligible importance (K. Krohme, personal communication, 6. March 2024). This opinion is based on the expert’s own experience managing the apple orchard of the “Kreislehrgarten Steinfurt” (i.e. a horticultural facility for public education and professional training), which is 3 km from the study site.

The consultation of experts in the field of irrigation systems led to no satisfactory result. A reduction in uncertainty for the risk of damage to the irrigation system could not be achieved due to resource limitations and time limitations of the expert. This is why the associated risk is not included in the mathematical model. The possible occurrence of damages on the drip irrigation system and the resulting irregular costs are of enough relevance to be kept in the conceptual model to be quantified in the future.

The variable "arable risk" was also not directly considered in the mathematical model. This is due to the high level of uncertainty regarding future weather and the associated effects on yield. However, since the value ranges of the arable yield variables are based on observational data from the study region, the variability in yield associated with varying weather conditions is considered to be captured within the model.

The interviewed expert considered the effect of the tree rows on the arable crop to be small. This is due to the thorough system composition and management concept, designed to minimize negative effects such as shading and water and nutrient competition. A "slight positive effect" in crop yield in years of drought is considered possible by the interviewed AF expert but has not been quantified (B. Kayser, personal communication, 28. February 2024).

4.2. The basic decision

The simulation of the basic decision, i.e., the binary choice whether to establish the apple AF system or not, is depicted below. Plotting the NPV of the baseline scenario (the treeless arable system), and the AF system allows for a first qualitative visual comparison of the outcome distributions (Fig. 7). The outcome distributions shown are generated via Monte Carlo simulations and are the result of 10,000 simulation runs. The x-axis shows the NPV, which is the result of the summation of the discounted cash flows for each of the 30 simulation years. The values are to be interpreted as the NPV in 1,000 € per ha of AF system, which is 10.14 ha in size. The generated NPV is therefore 10,140 times what is depicted on the x-axis. The presentation of the NPV per ha was chosen, as the profitability of agricultural systems is usually depicted on a per ha basis. This ensures easy comparability with other agricultural systems and studies. The division of the output data by 1,000 ensures for better visibility of the values on the x-axis. The probability of occurrence is depicted on the y-axis. The higher the value represented on the y-axis of the graph, the greater the likelihood of occurrence for the corresponding value on the x-axis.

By comparing the 90 % confidence intervals (CI) of the output distributions (NPV) for both systems, valuable information about the risk and uncertainty associated with the decision can be obtained. Tab. 1 presents a summary of the important statistics to consider when comparing the distributions. The 90 % CI of the baseline system, ranges from 23.58 K€/ha to 48.02 K€/ha, suggesting a relatively narrow range of potential outcome values. Conversely, the CI of the AF intervention scenario spans from -16.76 K€/ha to 97.89 K€/ha, indicating a broader spectrum of possible outcomes. While a potentially 2.03 times higher NPV can be obtained through the AF intervention, the outcome might equally likely result in a significant net loss. The wide distribution in NPV because of the implementation of the AF system, indicates a high uncertainty in possible outcomes.

When assessing the decision-associated risk, the probability of occurrence of the negative values is to be taken into consideration. Since the 5th percentile of the distribution (i.e. the value below which 5 % of all values are) has a low probability of occurrence, the interquartile range (IQR) and median are to be considered. The IQR is the value range between the 1st quartile (25th percentile) and 3rd quartile (75th percentile), in which 50 % of all values of the distribution lie. The examination of this metric might have a higher informative value in a decision-making process, since the respective values of the IQR have a greater likelihood of depicting the true outcome than the outer values of the 90 % CI. The NPV of the treeless baseline scenario expresses an IQR of 29,54 K€/ha to 39.14 K€/ha with a median value of 34.19 K€/ha. The NPV of the AF intervention scenario has an IQR of 8.33 K€/ha to 54.03 K€/ha, with a median of 29.40. K€/ha. These findings support the before given statement, that the outcome of the AF intervention scenario is associated with a higher variability and therefore a higher uncertainty.

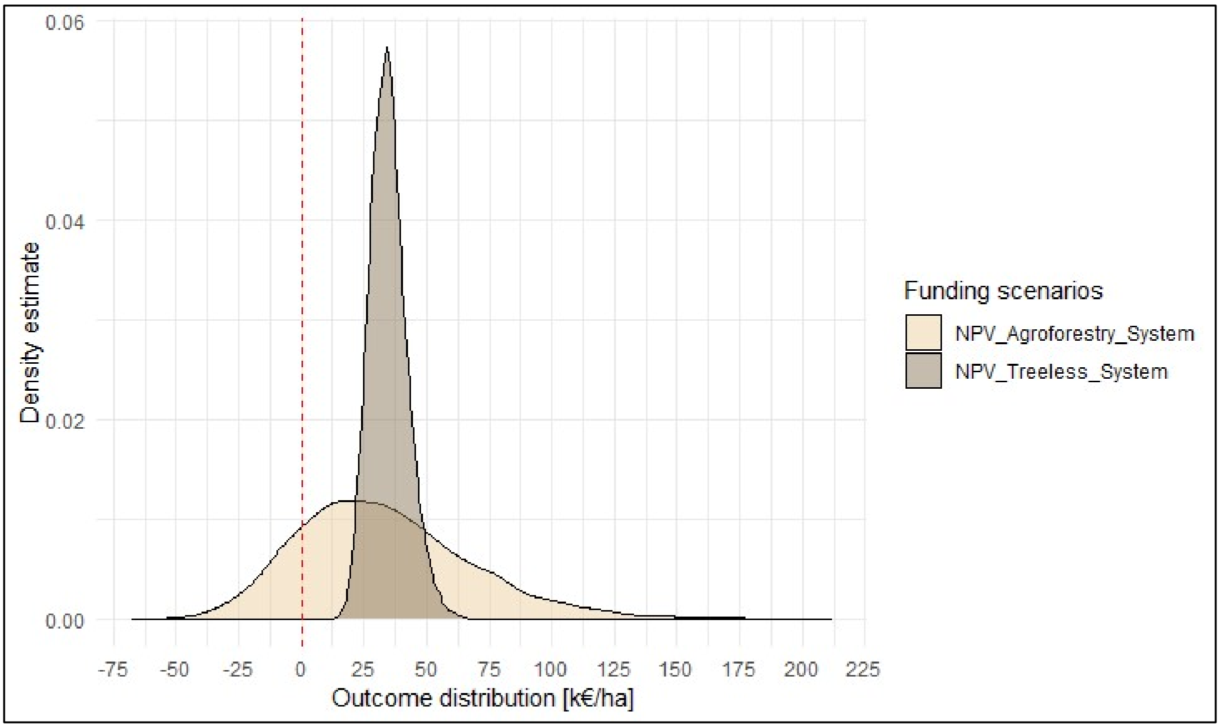

Figure 7: Monte Carlo simulation outcome distributions depicting the NPV of the baseline scenario (NPV_Treeless_System) and the NPV of the intervention scenario (NPV_Agroforestry_System).

Table 1: Summary statistics for the output distributions of the treeless baseline system and the agroforestry intervention system. The values represent the NPV in 1,000 €/ha.

	Treeless baseline system	Agroforestry system
Min.	13.62	-67.48
5th Percentile	23.58	-16.76
25th Percentile	29.54	8.33
Median	34.19	29.40
75th Percentile	39.14	54.03
95th Percentile	48.02	97.89
Max.	72.37	212.32

By subtracting the net cash flows of the treeless system from the net cash flows of the AF system, the NPV of the decision itself, or “trade-off”-NPV can be calculated. Plotting this trade-off-NPV (Fig. 8), provides further information on the effect of the intervention onto the NPV, thereby offering additional information for the comparison of the scenarios.

The axes of Fig. 8 are to be interpreted analogously to Fig. 7. The distribution follows roughly a bell-shape while being skewed to the right (skewness = 0.70). The distribution contains positive as well as negative values, indicating that the probability of the intervention being the objectively less desirable choice being > 0. Overall, 62.64 % of all values are positive. The 90 % CI ranging from -30.61 K€/ha to 80.85 K€/ha (Tab. 2). The boxplot integrated into Fig. 6 shows, that the IQR is predominantly positive, but does contain negative values, i.e., -6.15–38.93 K€/ha. The vertical line within the boxplot represents the median, which has a positive value of 14.63 K€/ha.

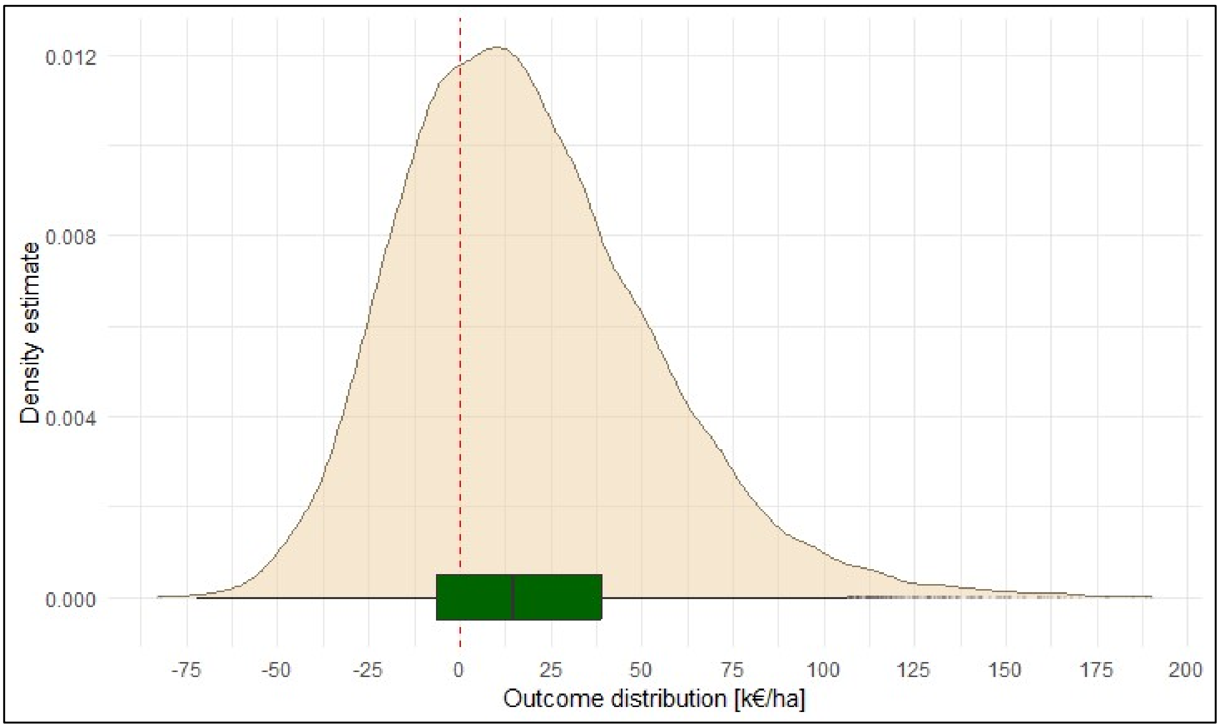

Figure 8: NPV of the decision, i.e. the NPV of the difference of the net cash flows of the baseline and the intervention system.

Table 2: Summary statistics of the output distribution of the analysed decision, i.e. whether to establish the examined AF system. The values represent the NPV in 1,000 €/ha.

	Decision
Min.	-82.86
5th Percentile	-30.61
25th Percentile	-6.15
Median	14.63
75th Percentile	38.93
95th Percentile	80.85
Max.	190.37

Examining the cumulative cash flow generated in the simulation of the AF system (Fig. 9), provides further decision-relevant information. The median, as well as the outer most values of the confidence intervals depicted in Fig. 9, each create a curve, which can be separately considered. Here, the median as well as the curves made up by the values on either side of the IQR exhibit a strictly monotonic increase. This indicates that the net cash flows of each year are positive in at least in 50 % of the simulated cases. The median, as well as the values directly surrounding it, represent the outcome with the highest likelihood of occurrence and can therefore be used as an indication of the expected financial performance of the AF system. However, considering the variability of the outcome values is crucial, when assessing the risk associated with an analysed decision. It is therefore imperative that the CIs mentioned above be taken into account, as well as their progression and total range. As the duration of the simulation increases, the confidence intervals show increasingly large bandwidths. The uncertainty therefore logically increases over time. The intercepts of the curves with the x-axis provide information of the length of the payback period of the investment, i.e. the time it takes for the investment to have paid off. Based on the simulation, there is a 90 % probability that the payback period of the AF investment without any funding will have a duration of 3 to >30 years. In 50 % of the simulated cases, the payback period has a duration of 5–9, with the median payback period being 6 years long (Tab. 3).

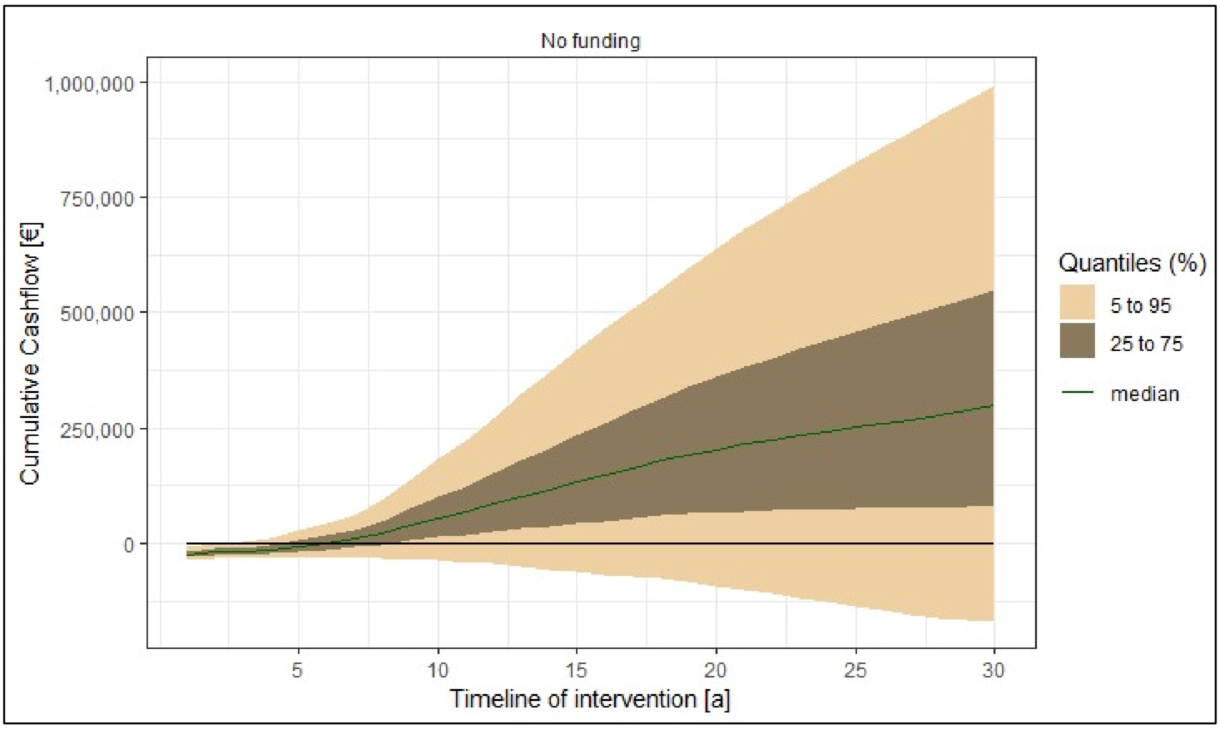

Figure 9: Cumulative cashflow of the AF system without any funding.

The assessment of the output distributions (Fig. 5, 6) and the cumulative cashflow (Fig. 7) inform about possible decision outcomes and their associated likelihoods of occurrence. However, these metrics do not inform about key uncertainties associated with the input variables of the model. The input variables that influence the output distribution most strongly is assessed via a sensitivity analysis. The Variable Importance in Projection (VIP) is depicted in Fig. 8. It informs about input variables that have the highest explanatory values for changes in the output distribution depicted in Fig. 6. Sensitivity analysis outputs which exceed a certain threshold (here 1, see vertical line in Fig. 8), can be considered of key importance to the simulation outcome. Additionally, it can be assessed if the impact of an input variable is positive or negative.

For the basic decision, whether to implement the specific apple AF system, all input variables of high importance are related to the apple production. The max. apple yield (apple_yield_max) has the highest VIP score, followed by the price of apples with table apple quality (table_apple_price). Both variables have a strong positive impact on the outcome variable, NPV. Also, important is the proportion of the apple harvest that is of table apple quality (perc_table_apple). The NPV is negatively influenced by the cost associated to the apple harvest (apple_harvest).

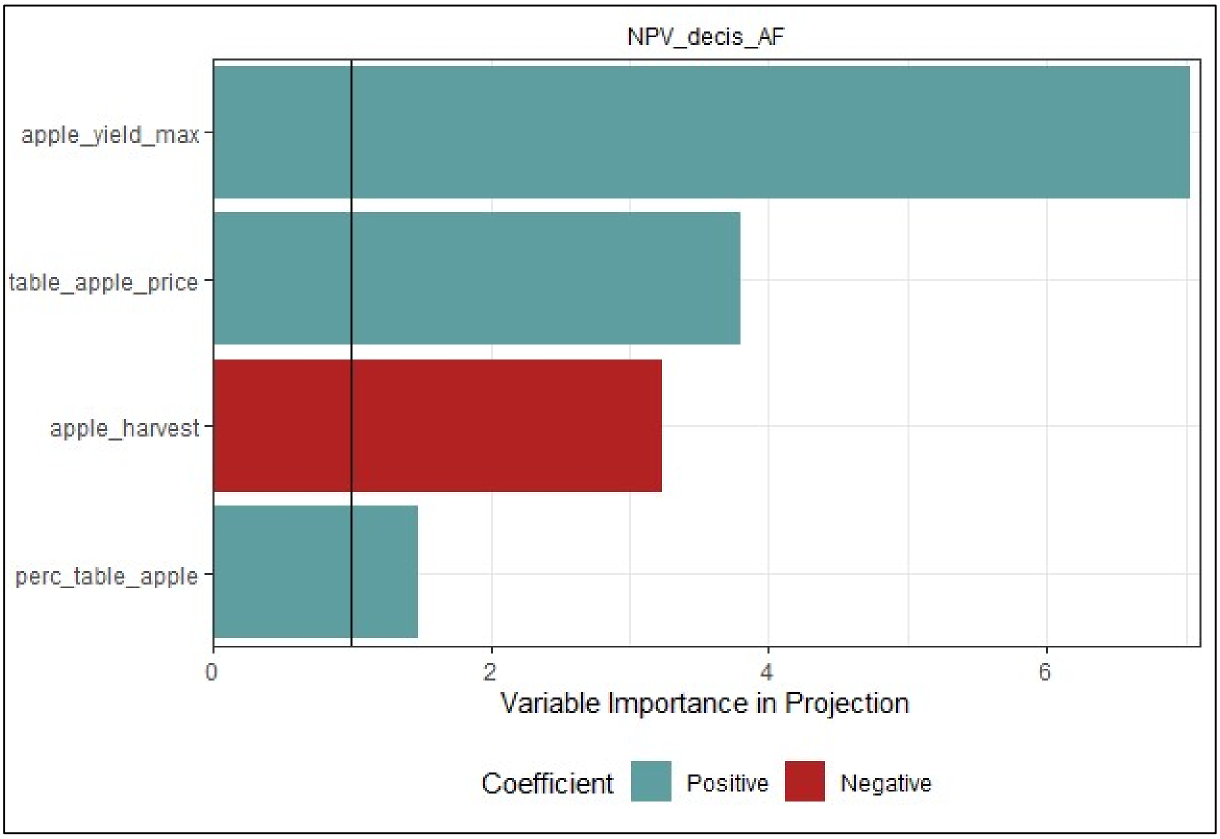

Figure 10: Sensitivity analysis output. Portrayed is the magnitude of influence of the input variables on the outcome variable (NPV of the decision). Input variables with sensitivity values > 1 (vertical black line) are considered to be key uncertainties for the decision.

The results of the sensitivity analysis, the VIP scores, provide qualitative information about which uncertainties are the most important to consider in the decision-making process. They do not, however, quantify the value of the reduction in uncertainty. This information is obtained by a further analysis, the calculation of the Expected Value of Perfect Information (EVPI, Fig. 9). This metric provides a quantitative estimation of the amount of resources a decision maker should be willing to invest into the elimination of uncertainty.

The value of perfect information is expressed in monetary terms. The precise prediction of the max. apple yield is worth 31,581.30 €. Elimination uncertainty regarding the price for which apples of table apple quality can be sold is worth 6,385.37 €. Predicting the costs associated to the apple harvest is worth 2,995.60 €. Accurately forecasting the percentage of table apples within the total apple harvest is worth 7.25 €. The reduction of uncertainty regarding the productivity and the revenue potential of the AF tree strips, is of utmost importance to the decision-making process.

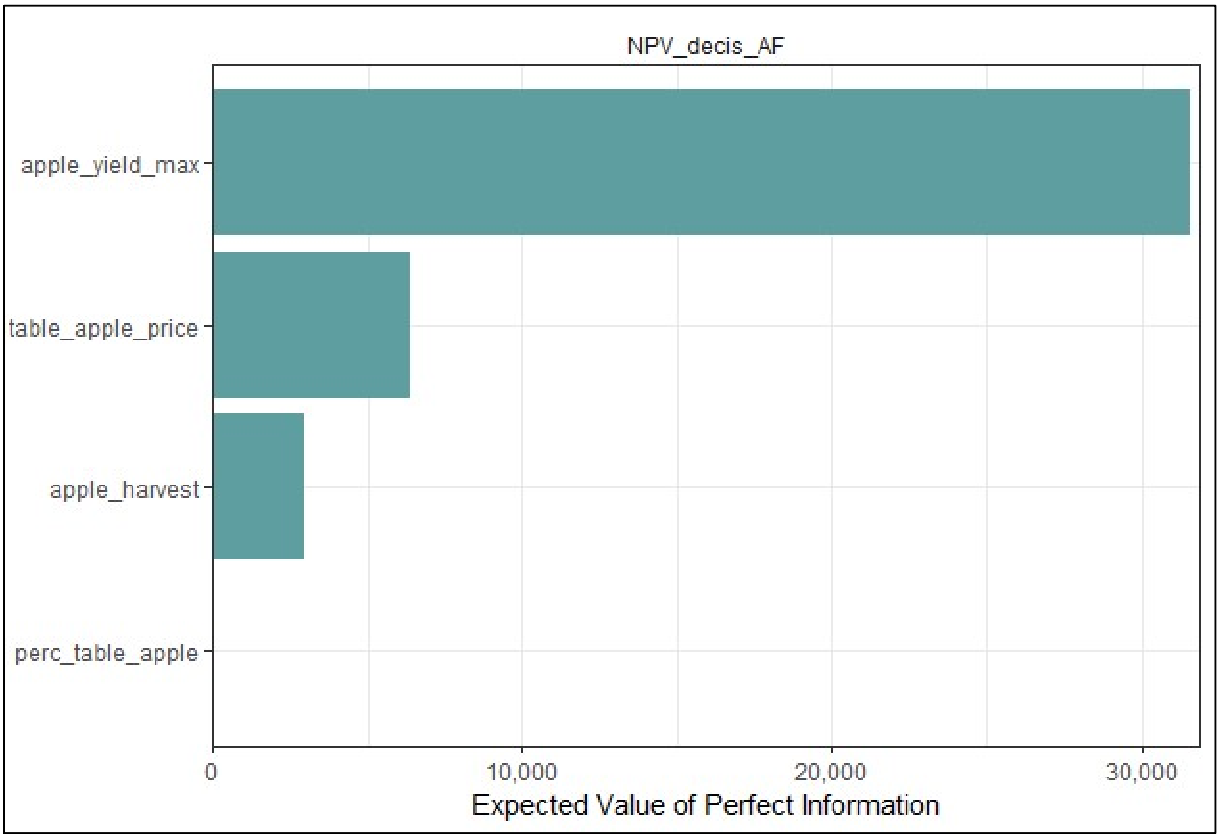

Figure 11: Quantitative information about the value of uncertainty reduction. The Expected Value of Perfect Information provides information about how much a reasonable decision maker should be willing to invest into the elimination of uncertainty in a single variable.

4.3. Comparison of funding scenarios

Modelling the AF system and examining the impact of its implementation onto decision-relevant outcome variables, allows for a better-informed decision-making process by e.g. a farmer facing a similar decision. However, farmers from different regions of Germany, may have access to funding, which has not been taken into consideration in the first analysis of the decision. Funding, especially investment support schemes, might contribute considerably to economic metrics, such as the NPV, cumulative cash flow and thereby the duration of the payback period of the investment. Considering funding is therefore important from two perspectives: a) the lower the initial investment and the higher the annual returns of the AF intervention are, the more convinced a farmer might be to establish the AF system; b) examining the effect of the funding scheme onto decision-relevant output metrics, provides information which can be used for designing better suited policies to support regional, national or EU goals of rural development.

A pairwise comparison of the NPVs of the AF system in each funding scenario with the NPV of the baseline scenario, provides information on the effect of the funding scheme on the decision value (Fig. 8). Fig. 8 depicts the simulated NPVs of the decision made in 10 different scenarios. These scenarios are based on funding schemes available Germany as well as one funding scheme suggested by DeFAF (see: *2.3.2.2.–2.3.2.9.*) Tab. 4 provides another overview of what the funding schemes encompass and how they would affect the examined AF system, i.e., how much funding the farmer would receive for his established AF system. The effectively generated funding amounts vary between scenarios (Tab. 4) ranging from 0 (No funding), only an annual subsidy of 114 €/ha of wooded area (Only ES 3, SN) to over 35,000 € of investment support (i.e., 100 % of investment cost in the DeFAF-Suggestions scenario). The scenarios do all depict an almost identical distribution with min. and max. values of ~ -82 K€/ha and ~190 K€/ha, respectively (Tab. 3). The funding scenario based on DeFAF suggestions shows the same distribution spanning over ~270 units but shifted to the right, expressing higher values across the distribution. The effect of the different funding schemes is low, depicted e.g. by the difference in the median NPV. It ranges from 14.63 K€/ha without any funding to 15.73 K€/ha in the NI funding scenario. Only the DeFAF suggested funding increases the median NPV considerably to 19.62 K€/ha (Tab. 3). All boxes, and therefore all IQR's and medians of the simulated scenarios express positive as well as negative values. Tab. 3 presents an overview of the distributions generated for each scenario. Again, only the scenario based on the DeFAF's suggestion shows considerable differences. However, also this scenario generates negative values, with the lower range of the IQR taking on values of -1.15 K€/ha.

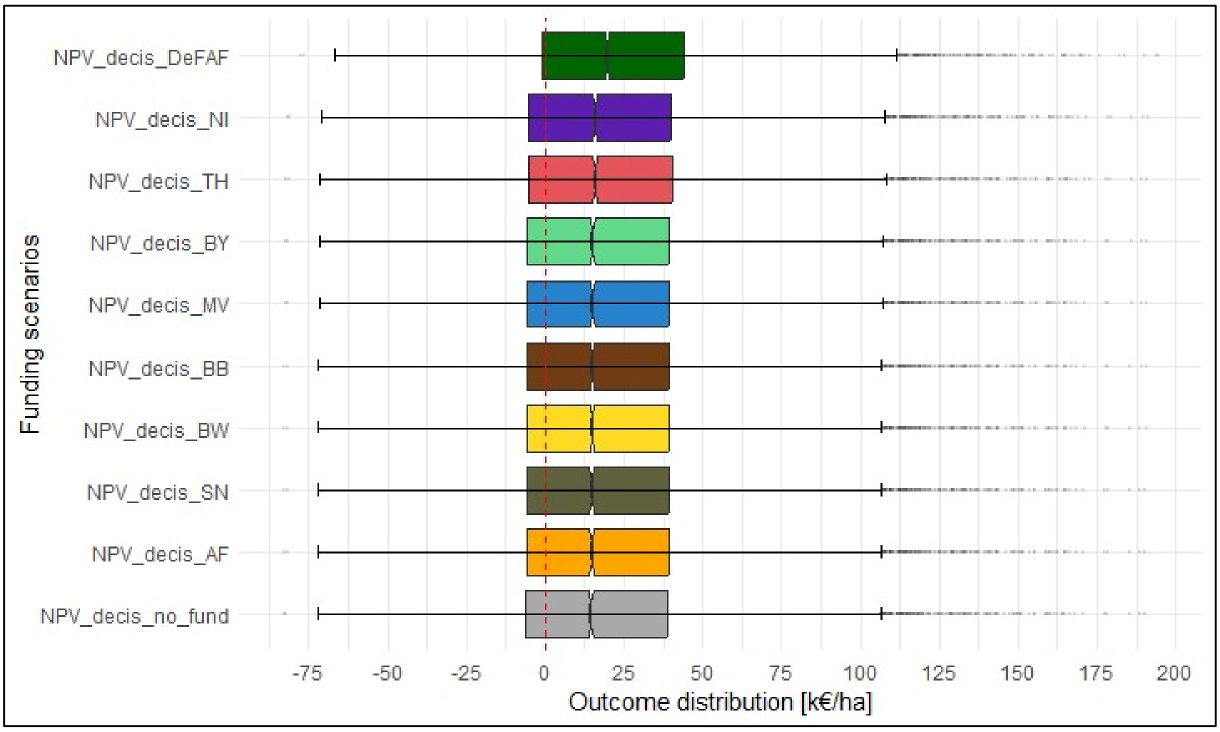

*Figure 12: NPV of the decision in each funding scenario, i.e. pairwise comparison of the NPV of the baseline system and the NPV of the AF system across funding scenarios. The boxes indicate the location of 50 % of all values generated by the Monte Carlo simulations (i.e. the interquartile range (IQR). The vertical line within the box represents the median, i.e., the value where 50% of all values are smaller and 50% of all values are larger. The notches surrounding the median extend 1.58 * IQR / $n^{1/2}$. This allows for a comparison between medians: if notches of two boxplots do not overlap, significance is indicated. The whiskers, i.e. the horizontal line, represent the location of 25 % of the lowest values (i.e. the lowest quartile) and 25 % of the largest values (i.e. the upper quartile). The whiskers extend no further than 1.5 * IQR. The black dots represent values, classified as outliers, which lie outside of the range of the whiskers (> 1.5 * IQR) (WICKHAM ET AL., 2024).*

Table 3: Summary statistics of the output distribution of the decision in each funding scenario. "D." = "decision". "D. no fund" = scenario "NPV_decis_AF" in Fig.8 The values represent the NPV in 1,000 €/ha.

	D. no fund	D. AF ES 3	D. SN	D. BW	D. BB	D. MV	D. BY	D. TH	D. NI	D. DeFAF
Min.	-82.86	-82.61	-82.61	-82.46	-82.46	-82.32	-82.32	-82.08	-81.75	-77.18
5th Percentile	-30.61	-30.42	-30.42	-30.28	-30.28	-30.13	-30.13	-30.02	-29.55	-25.79
25th Percentile	-6.25	-5.97	-5.97	-5.83	-5.82	-5.67	-5.68	-5.14	-5.07	-1.15
Median	14.63	14.81	14.81	14.94	14.95	15.10	15.10	15.70	15.73	19.62
75th Percentile	38.93	39.11	39.11	39.21	39.22	39.40	39.40	40.13	40.05	43.95
95th Percentile	80.85	81.35	81.06	81.20	81.20	81.35	81.35	82.27	81.94	86.07
Max.	190.37	190.55	190.55	190.64	190.66	190.84	190.66	190.66	191.33	194.59

A comparison of the simulated cumulative cash flow of the AF system under different funding conditions (Fig. 9–11) confirms the similarity between the scenarios visible in Fig. 8. Other than for the funding scenario based on the suggestions of DeFAF, all cash flows express little differences. The higher effective funding of Lower Saxony (Tab. 4) indeed causes a notable visible effect in the curves (Fig. 11).

Examining the intercepts of each curve of each funding scenario shows little effect of the different funding schemes. The payback period does indeed differ across the funding scenarios, but shows such small differences, that a considerable effect of the funding is questionable. In 90 % of simulated cases, the payback period of the scenarios with only ES3 funding, has a duration of 3 to >30 years (30 years being the length of the simulation). This is equal to the funding scenario with no funding at all and the Brandenburg funding scenario. Five scenarios, namely Baden-Württemberg funding, Bavaria funding, Mecklenburg-Western Pomerania funding, Saxony funding and Thuringia funding show payback periods of 2 to >30 years in 90 % of the simulated cases. However, the effective funding for the examined AF system in the scenario Saxony funding is limited to only the ES 3 funding, because of requirements of the funding scheme, which the modelled AF system does not meet. This means, a payback period with a duration equally as high as in the scenario with only ES 3 would be expected. The difference of 3 to >30 years to 2 to >30 years in the scenarios Only ES 3 and Saxony funding, respectively, is therefore likely caused by the probabilistic nature of the model and not by a true effect of the funding scheme. This must be taken into consideration, when comparing all other funding schemes by this metric. Lower Saxony's funding leads to a payback period of 1 to >30 years in 90 % of the simulated cased and may thereby be considerably shorter than that of other scenarios.

The payback period is not a metric, that allows for the comparison of the funding scenario based on the suggestions of DeFAF with other scenarios, since in the DeFAF scenario, 100 % of the investment is subsidised. This means, there is no investment of which a payback period can be calculated. A positive cumulative cash flow is depicted as early as year 1 and for the 5th, 25th, 50th, and 75th percentile (Tab. 4). The 90th percentile expresses only positive values in year 3 but includes negative values every year after that, indicating the possibility of a net negative cumulative cash flow for most of the simulation period (i.e. years 1, 2, 4–30).

Examining the 75 % CI as well as the median, a similar hierarchy is depicted, with clear differences only visible for the scenario based on Lower Saxony's funding scheme. The Lower Saxony funding scenario expresses a median payback period of 5 years, with a 75 % CI of 3–7 years. All other funding scenarios depict median pay back periods of 6 years and a 75 % CI of either 5–9 years (No funding, Only ES 3), 5–7 years (BY, BB, MV, SN, TH) or 4–7 years (BW).

*Table 4: Summary table of simulated funding scenarios. Depicted are the characteristics of the funding measures, the effective funding for the examined AF system and the estimated payback period for the respective scenario, i.e. the time in years it takes to generate a positive cumulative cash flow. *Funding sum depends on the amount of investment cost. **Eligible costs refer only to cost associated with planning/consulting. ***Eligible cost explicitly excludes planning/consulting.*

Funding Scenario	**Investment funding scheme**					**Annual funding**	**Effective funding for examined system**		**Payback period [a]**		
	%	Max. [€]	Differentiation				Invest [€]	Annual [€/ha]	90%CI	75%CI	Median
No funding	0	0		non		0	0	0	3– >30	5–9	6
Only ES 3	0	0		non		200	0	114	3– >30	5–9	6
BW	80	1,500		non		200	800–1,500	114	2– >30	4–7	6
			SRC	Shrubs	Food/timber	200					
BY	65	50,000	1,566 €/ha	4138 €/ha	5,271 €/ha		3,004.47	114	2– >30	5–7	6
BB	100**	1,530		non		200	800–1,530	114	3– >30	5–7	6
NI	40***	20,000		non		200	8,441.09–17,319.44	114	1– >30	3–7	5
			SRC	Shrubs	Food/timber	200					
MV	65	300,000	1,566 €/ha	4138 €/ha	5,271 €/ha		3,004.47	114	2– >30	5–7	6
SN	40	5,000,000		non		200	0	114	2– >30	5–7	6
TH	100	6,000		non		200	800–6,000	114	2– >30	5–7	6
DeFAF-Suggestions	100	X		non		600 (+200)	26,088.74–35,530.02*	456	1– >30	1–1	1

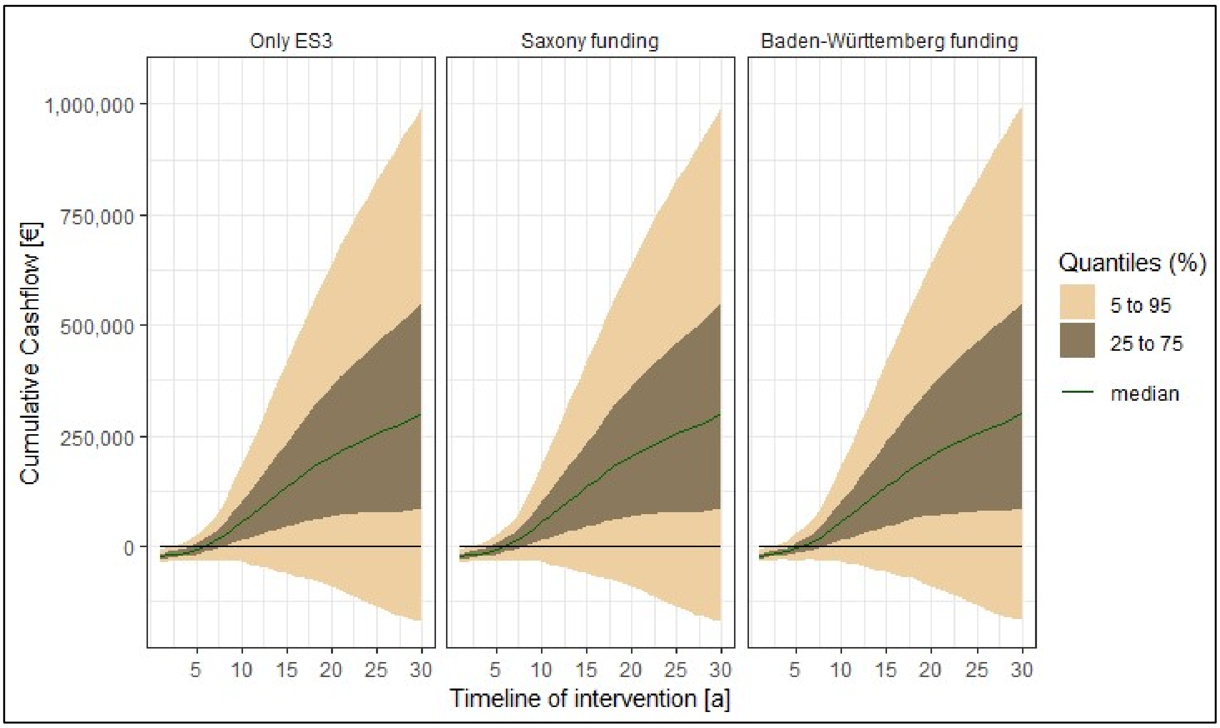

Figure 13: Comparison of cumulative cash flows of the AF system under different funding scenarios. Here: exclusively annual support (ES 3), funding available in Saxony, and funding available in Baden-Württemberg.

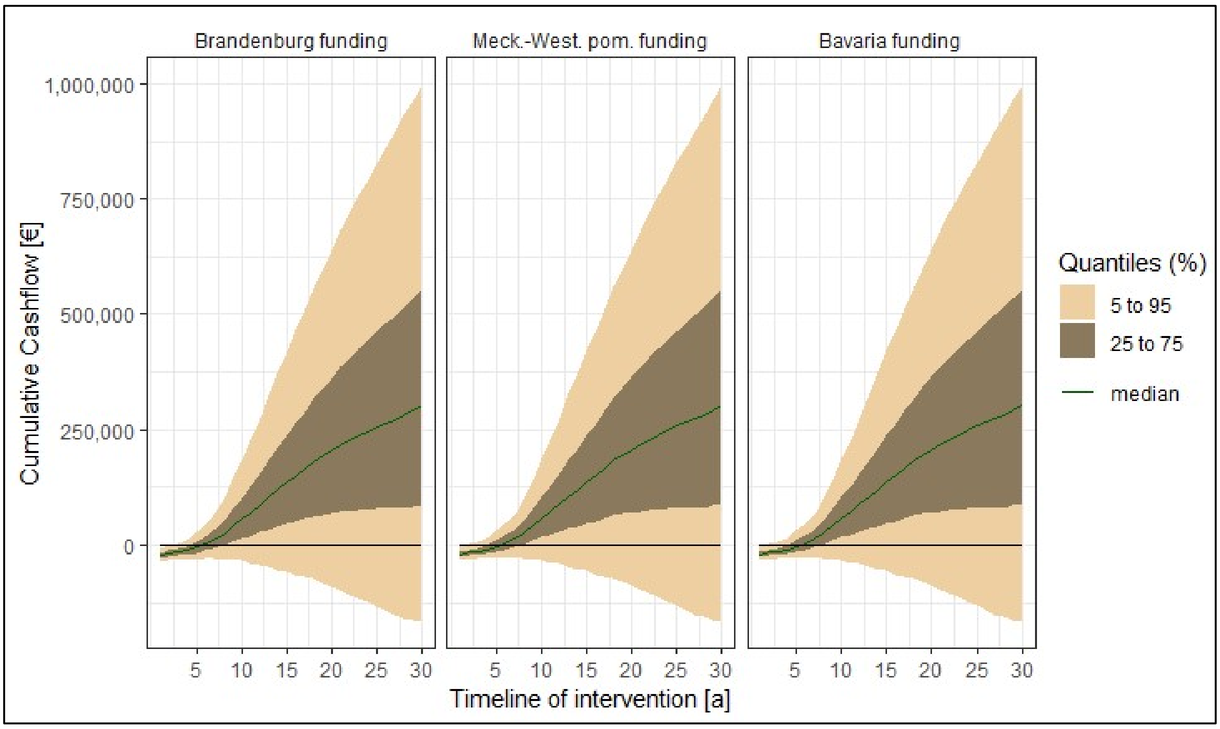

Figure 14: Comparison of cumulative cash flows of the AF system under different funding scenarios. Here: funding available in Brandenburg/Berlin, funding available in Mecklenburg-Western Pomerania, and funding available in Bavaria.

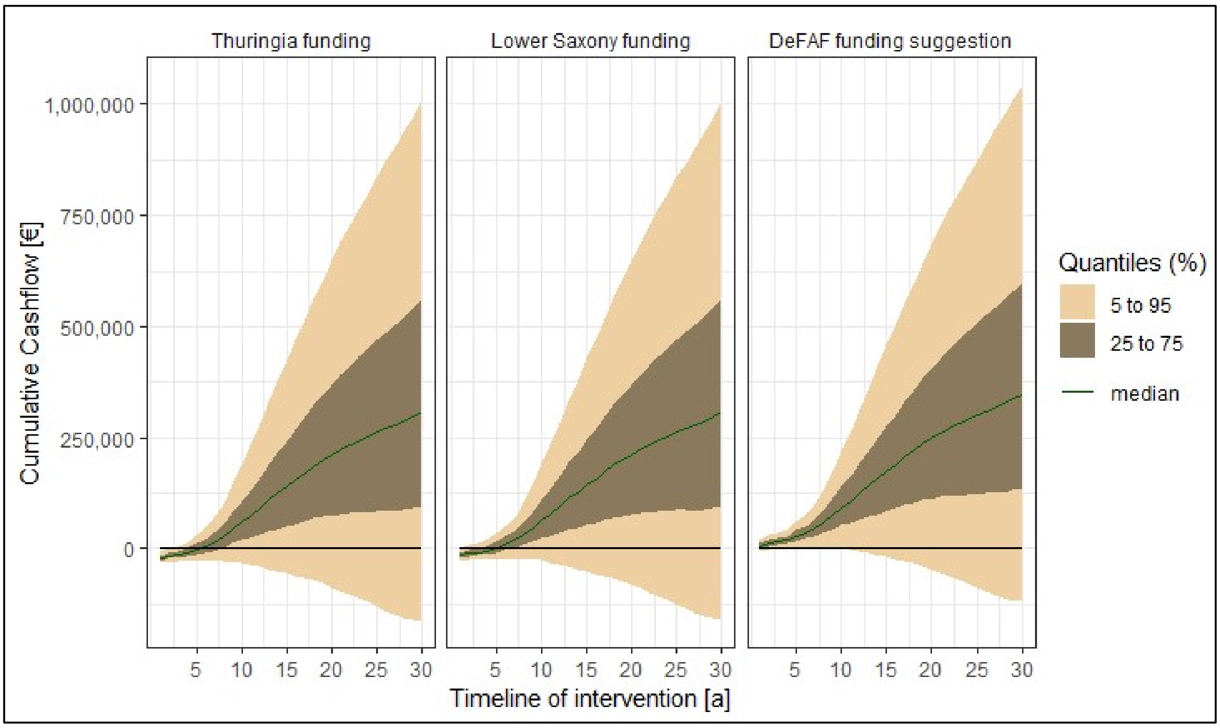

Figure 15: Comparison of cumulative cash flows of the AF system under different funding scenarios. Here: funding available in Thuringia, funding available in Lower Saxony, and funding based on the suggestions of DeFAF.

5. Discussion

Comparing the output distributions of the NPV of the baseline system and the AF shows clear differences between the options (Fig. 7). The distribution of the AF systems NPV is considerably wider, with the 90 % CI being 4.7 times larger than that of the baseline system. The 90 % CI of the AF system shows positive as well as negative values, while that of the baseline system is entirely positive. The IQR of the AF system depicts no negative values but is 4.7 times larger than that of the baseline system. The distribution of the NPV for the AF system indicates the potential for higher outcome values compared to the baseline system, with the 75th percentile, 95th percentile, and max. value being 1.4, 2, and 3 times larger, respectively, than those of the baseline system.

Subtracting the net cash flows of the baseline system from the net cash flows of the AF system allows for the calculation of the NPV of the decision (Fig. 8). It shows positive as well as negative values. The 90 % CI contains positive and negative values. The IQR is predominantly positive but does contain negative values as well. The median is positive.

Calculating the cumulative cashflow of the decision provides information about the payback period of the investment associated with the establishment of the AF system (Fig. 9). Since all values are the output of a Monte Carlo simulation, the cumulative cashflows are presented probabilistically. The 90 % CI of the payback period is 3 to >30 years. The IQR of the payback period lies between 5 and 9 years, meaning that in 50 % of the simulated cases, the payback period lies between these values. The median payback period is 6 years.

Key uncertainties associated with the decision whether to implement the examined AF system are provided by the VoI analysis (Fig. 10, 11). The model output (NPV of the decision) is most sensitive to changes in the variables associated with the realised profits from the apple production. Most important for the overall reduction in uncertainty is obtaining additional knowledge about the expected apple yields in the AF system. What proportion of the total apple harvest can be considered table apples and the price for which these apples can be sold is again highly relevant to reducing the overall uncertainty of the decision. Important to the decision is also the cost associated with harvesting the apples.

A pairwise comparison of the NPVs of the AF system and the baseline system across 10 different funding scenarios gives insight into how the funding schemes affect the NPV of the decision (Fig. 12). The distributions are nearly identical across all 10 funding scenarios, spanning ~270 units (K€/ha). All scenarios based on available funding schemes in Germany portrait small effects of the monetary support schemes. Only the funding suggested by DeFAF changes the placement of the distribution on the x-axis considerably. The NPV distribution is shifted to the right by ~5 units. However, the IQR of all 10 distributions includes negative values.

The effect of the funding measure on the duration of the payback period of the investment is again, small (Tab.4). While the payback period in the scenario with no funding has a median value of 6 years, it reduces to 5 years only in the NI funding scenario. Due to the fact, that the DeFAF funding scenario contains the subsidy of 100 % of the investment cost, the concept of payback period does not apply here.

While interpreting the results, the respective decision maker, who is supported by the analysis is to be considered. The comparison of the NPV generated by the AF system and the baseline systems serves as decision support for a farmer, who is deciding whether to implement the AF system. Comparing the NPVs of the decision across funding scenarios provides information on whether the funding schemes achieve the intended effect of providing adequate support and creating and enabling environment for farmers interested in AF. The availability of funding can be decision-relevant to a farmer but the impact of the funding schemes on the NPV can also provide insights into how funding schemes must be designed to encourage the adoption of AF. This is relevant information to a policy maker deciding what funding scheme to introduce to support the achievement of national goals.

The 4.7 times larger 90 % CI of the NPV of the AF system compared to the NPV of the baseline system suggests a considerably higher uncertainty regarding the true NPV generated by the

AF system. The negative values contained within the 90 % CI of the NPV of the AF system indicate the risk of making net loss with managing the AF system. However, the IQR of the NPV of the AF system is entirely positive, indicating the generation of a net profit through the management of the AF system in at least 50 % of the cases. Compared to the IQR of the baseline system, the IQR of the AF system is wider and does contain considerably lower values. This indicates a high uncertainty regarding whether the establishment of the AF system is the economically better choice. The narrow value range of the NPV of the baseline system, which is entirely positive indicates that keeping the system as it is, is the less risky choice.

The NPV of the decision itself gives clearer identification of what is the economically sounder choice, since negative values indicate that the baseline scenario is the more profitable option while positive values indicate that the AF intervention outperforms the baseline system. The wide distribution shows a high uncertainty with a considerable portion of the distribution being negative (Fig. 8). The moderate positive skewness of 0.7 shows that the distribution has a longer tail on the right side, indicating that the distribution is pulled towards higher values. This means, that the simulation output depicts the establishment of the AF system as the better option in most of the cases. In fact, the positioning of the distribution on the x-axis indicates that the AF system will outperform the baseline system in 67.64 % of the 10,000 simulated cases. However, given that there is still a considerable chance of the baseline scenario outperforming the AF system (32.36 %), the decision is still fraught with risk and the respective decision maker must consider their own willingness to accept that risk. The higher probability of positive outcomes might convince risk-seeking decision makers. Risk-averse decision makers might give a high weight to the fact, that the 25^{th} percentile is negative and may choose to remain with the baseline system. This is especially true when considering, that the baseline system does not generate negative NPV values in any of the 10,000 simulated cased, while the AF system does (although not within the IQR) (Fig. 7).

To offer sufficient decision support, a reduction in uncertainty is recommended. This is best done by reducing the uncertainty of the variables associated with the apple production. The VoI analysis shows a high potential for a reduction in overall uncertainty by investing additional resources into narrowing the value ranges of the potential apple yields, the potential apple quality and the apple prices that can be achieved. A reduction in uncertainty here might already result in a clearer picture and convince risk-averse farmers to adopt an AF system such as the examined apple AF system. This would, however, only be the case if further analysis would show that high apple yields and thereby high profits could be achieved with a satisfactory amount of certainty. If further analysis indicates a high probability of obtaining low apple yields, the AF system might become the more obviously unfavourable choice.

The comparison of the 10 funding scenarios indicates, that the effect of the existing funding schemes on the NPV is negligible when examining a 30-year period. The simulation therefore suggests that the availability of funding is not crucial to the decision whether to implement the AF system or not. If the funding scheme based on the suggestions of DeFAF were to be available for German farmers, it would be of greater importance than all existing funding schemes. Its effect is larger and leads to a higher probability of the AF system outperforming the baseline system (73.66 % vs. 67.64 % in the scenario with no funding). However, a risk-averse farmer might still shy away from the establishment of the AF system, since 26.34 % of all simulated cases indicate, that the baseline system outperforms the AF system, even with DeFAF-funding.

The simulation results confirm earlier comments by AF stakeholders such as DeFAF, which emphasised that a subsidy of 200 €/ha of wooded area was too low to compensate for the higher management expenses related to AF (BÖHM, 2023; Böhm et al., 2023). It indeed does not affect the NPV of the decision in a way that would be of importance to a decision-making farmer. The results also support the suggestion by DeFAF to fund 100 % of the establishment costs of AF systems to create an enabling, encouraging environment for farmers (Böhm et al., 2023). Only the 100 % investment support and the increased annual funding raised the NPV of the AF system considerably (Fig. 12). Policy makers should therefore consider the lack of effect by the existing funding schemes and consider using the potential 100 % investment support, allowed by the EU and the GAK.

Important to note is, that the informative value of the model depends heavily on how detailed it was created and, above all, on whether all decision-relevant factors were recorded. It must, therefore, be considered that the following factors are *not* included in the model. The model does try to capture the most relevant economic factors of the decision. It does not, however, provide a holistic picture of all benefits provided by the AF system. Socio-ecological factors such as the creation of habitat, providing a food source for pollinators, building up soil organic carbon, reducing wind speeds and therefore erosion, or creating a more structured landscape, therefore adding to its aesthetic were not quantified and not added to the model. Negative microclimatic effects of the tree rows in humid years, leading to higher risk of fungal infection in the arable crop were not included, neither were positive microclimatic effects in dry years, leading to reduced water stress in the arable crop compared to an open field. All these factors might be relevant to the decision.

Due to a lack of information on the risk of damages occurring in the drip irrigation system, this potentially decision-relevant factor was not included in the mathematical model. If regular repairs are needed, this could drive up the management cost of the AF system and thereby, lower the profit achievable. The risk of mechanically induced damage occurring cannot be considered 0 and is therefore to be further examined.

Apple specific risks such as the mismanagement of apple trees due to the lack of experience by the farmer and his employees was also not considered in the model. A faulty pruning could lead to reduced yields or even alternate bearing in the apple trees, leading to a higher labour intensity in the following years, trying to fix the mistake. An extensive training in pruning and tree management is included in the investment cost, but the risk of errors is not 0, especially in the initial phase, when experience is still low. The different characteristics of the 9 different apple varieties were not considered. Even growth and yield characteristics were assumed across cultivars. Importantly, it was assumed, that 100 % of the picked apple yield is always sold. This might not be the case. A certain percentage of apples might get damaged during the transport to the shop or during storage.

Important to note is that for all subsidy schemes, which fund a certain percentage of the investment cost, the gross cost was the basis for the calculation. Saxony's funding scheme explicitly states that net costs are the calculation basis. Other federal states do not clearly state if the gross or the net costs are taken as the basis for the calculation of the subsidy. Moreover, the expected time of payment of the subsidy has not been taken into account. Saxony states, that farmers must cover the investment costs in advance, even if they are subsequently covered by the subsidy. Taking this into consideration in the calculation of cash flows and subsequently the NPV can change the outcome, because later received subsidy payments would have to be discounted and therefore lose value. In a real-life situation, the advance payment of the later funded investment cost can be of relevance to the decision-maker, depending on the size of the investment and the farming operations liquidity.

More abstract positive effects, such as the improved image and marketing of the farm were also not considered. However, the establishment of the AF system already led to cooperations with local shops, which opened the opportunity to grow different crops (rye for breadmaking) and sell them for a better price than what could be achieved in wholesale marketing (J. Grosse-Kleimann, personal communication, 23. January 2024).

Since the aim of this thesis was to examine the change of the profitability of the AF system in various funding scenarios, it is considered justifiable to leave out the mentioned factors in the context of this thesis. However, the further examination of the mentioned points is intended.

The economically most important factors such as the investment costs were realistically captured and act as a plausible basis for the examination of the effects of the funding schemes. The basic model created in this thesis does therefore provide a first indication of the possible role the availability of funding plays in the decision-making process. The inclusion of all additional factors mentioned above may change the distribution of the NPV of the AF system and therefore of the NPV of the decision. However, the inclusion of the funding schemes into the model does not lead to changes the distribution but rather to its position on the x-axis by increasing values across the distribution evenly. This is because the funding amounts accounted into the calculation are fixed values in each scenario. They do not contribute to the uncertainty (width of the value range) of the outcome.

A truly holistic model, depicting all effects and services AF systems provide might serve as a basis for argumentation when convincing decision-makers to introduce effective subsidies for the establishment of AF systems. However, the national targets set in the GAP SP for the implementation of 65,000 ha of AF by 2027 indicate that policy makers no longer need to be convinced of the benefits of AF. Rather, it must be clarified what needs to be done to fulfil the self-imposed goals. The results of this thesis indicate that the effects of the available funding measures are small and that they should be revised in order for them to have a decision-relevant effect. It is highly recommended that the proposals of the DeFAF be used as a guide when drawing up future funding measures. Especially making use of the possibility of subsidising 100 % of the investment cost including the costs for planning and consulting seems imperative to the creation of an enabling environment.

It must be pointed out that covering the investment cost associated with establishing an AF system as well as an additional annual premium are not the only things to consider when striving for the creation of an enabling environment. “Insufficient funding” is only 1 of 5 institutional barriers highlighted in section 2.4.4., which must be addressed equally. Consultation services must be extended and promoted. The inherent adaptability of AF to local conditions must be encouraged and not restricted by strict distancing regulations, etc. The bureaucracy involved in registering an AF system must be reduced. Especially since other subsidised environmental measures do not require the same effort, e.g., providing a management concept, which must be approved by a competent authority. Finally, and of utmost importance, legal certainty regarding the establishment, management and removal of AF systems must be guaranteed. This requires revisions, at least in the BNatSchG, which guarantee that farmers can harvest or remove AF systems that have been established as such if necessary.

The model in this thesis can serve as an initial point of reference for further investigations. Here, the examined AF system was negligibly affected by the funding schemes. In AF systems in which the tree component delivers less profitable products, such as wood chips from a SRC, the subsidies could be more significant. The adequacy of the funding might therefore depend on the type of AF system. It is, therefore, recommended to repeat the process shown in this thesis of testing the influence of various support measures on the NPV of the decision with different AF system types. Creating a catalogue of detailed decision-models of representative AF system types and testing them across different funding scenarios can deliver a compelling basis for the formulation of policy recommendations. The scope of such a comparison can extend beyond the national level. For example, funding schemes across EU countries could that way be compared. However, the aforementioned limitations of the model used in this thesis must be taken into account. An extension of the model is imperative for a realistic representation of the AF system and the influence of the subsidies on the risk associated with the decision. At least the factors that can have a direct economic influence must be integrated into the model, e.g., the risk of extreme weather events damaging the arable crops and the apples, the risk of mechanical damages to the drip irrigation system and the need for manual repairs, the potential for alternate bearing of the apple trees and the potential for damages occurring to part of the apple harvest rendering them unsellable. Equivalent risks and potential reductions in profit must be considered for every modelled AF system type. If all relevant factors are captured by the model, the DA approach is a method that makes it possible to provide quantitative decision support with comparatively little effort.

6. Conclusion

With the 2023 CAP reform and the publication of the German CAP SP, Germany explicitly acknowledged the ecological services provided by AF systems. The SP makes it obvious, that the extension of AF practices is politically desired. The plan of funding 25,000 ha of AF via the newly introduced annual funding measure (ES 3), was however clearly missed. In fact, only 51 ha of AF were registered via the annual support scheme in 2023. A targeted approach to creating an enabling environment for farmers willing to establish and manage AF systems must be created as soon as possible. Only then, can Germany reach its national targets of funding 65,000 ha of AF until 2027. For that it is imperative to identify and remove present institutional barriers and test existing and future AF support measures for their adequacy in reaching the intended goal through holistic analysis involving stakeholders.

By focusing on the CAP and its implementation at the national level, this thesis has consolidated current institutional barriers to adopting AF systems in Germany and assessed the effectiveness of current funding measures in supporting farmers to implement AF systems. The main objectives of this thesis were to

A) analyse the positioning of AF within policy frameworks,
B) identify and evaluate barriers and funding options,
C) model the economic outcomes of these factors using Decision Analysis, and
D) provide recommendations for policy makers.

The findings from this thesis offer an insight on how to create an enabling policy-environment for farmers to integrate AF practices and subsequently for Germany to meet its targets from the CAP SP. The key findings of this thesis are:

A) AF can be found in European policy as early as 1986. The Resolution on Community Action in the Forestry sector of 1986 mentions AF as a potential transitional land use form to increase tree cover in the EU. In the CAP, AF was first introduced in 2005, where the respective regulation on rural development encourages MS to integrate a funding measure for the establishment of AF into the national and/or regional rural development plans. In the subsequent funding periods, with reforms in 2007 and 2014, it was suggested to fund 80% of the establishment cost of AF system. Only in 2023 did Germany integrate a nationally valid definition of AF systems and declare them as agricultural land use systems eligible for direct payments via the CAP.

B) With the introduction of the German AF definition, an annual funding scheme for the maintenance of AF systems on arable land and permanent pasture was introduced. The funding measure is part of the ES programme, which aims to renumerate ecological services provided by farmers via Pillar I finances. Additionally, 7 out of 13 funding regions in Germany introduced some form of investment support for the establishment of AF systems. While in 3 regions funding is limited to planning and consulting cost, 4 regions offer various support ranging from 40 to 65 % of eligible investment cost. None of the regions fully fund the establishment of AF system, although this is possible as per the respective EU regulation and the German GAK.

   Although many of the pre-2023 institutional barriers highlighted by AF stakeholders have been removed by the introduction of an official definition of AF in the German funding legislation, the creation of a truly enabling environment has not yet been achieved. Key hurdles are: i) insufficient funding, which does not compensate farmers for the additional management effort and investment cost, nor renumerate the socio-ecological services provided, ii) lack off (subsidised) consulting, which is an indication of a lack of knowledge and knowledge transfer, which is considered crucial in regards to a land use practice that requires planning years or even decades into the future, iii) restrictive AF definition, which does not allow for the use of the inherent strengths AF as a land use concept has, namely its adaptability to local economic, management and biophysical conditions, iv) excessive bureaucracy, which might discourage farmers from adopting AF practices as a means of enhancing the local ecology, bringing a competitive disadvantage to AF as an agri-environmental measure, v) potential conflicts between AF farmers and nature conservation stakeholders, since AF is not considered within nature conservation laws, which might make AF systems still susceptible to becoming legally protected landscape elements.

C) The decision analysis revealed that the NPV distribution for the AF system examined in this thesis, is considerably wider than that of the baseline system, indicating higher uncertainty in potential outcomes. While the AF system demonstrates the possibility of higher returns, it also carries the risk of significant losses. Although the simulation showed that the AF system outperforms the baseline system in over 60 % of the cases, a risk-averse farmer may still be deterred by the remaining risk. A payback period of 3 to over 30 years has been revealed by the probabilistic calculation. While the median value of 6 years indicates that the AF system can be financially viable, the respective timeframe is uncertain. The VoI analysis provided insights into key uncertainties, the reduction of which can improve the overall decision-supporting value of the model. Especially apple production variables, such as the overall yield and market prices, have a high influence on the NPV of the decision. The NPV of the decision was compared across 10 funding scenarios. Thus, the adequacy of the identified existing funding measures and a hypothetical funding measure, suggested by DeFAF, was assessed. The comparison revealed that the impact of the existing funding schemes on the NPV of the decision is small. This highlights the limited adequacy of the current policies to reduce economic risk and create an enabling environment. The DeFAF-scenario shifted the NPV distribution positively. However, even the suggested 100 % funding of all AF investment related cost and a significantly increased annual funding did not eliminate the possibility of the baseline system outperforming the AF system. Risk averse farmers might therefore be reluctant to adopt the examined AF system type even if the DeFAF-suggested funding was to be implemented in Germany.

D) Policy makers must take the above stated into account when working towards reaching the national target of funding 65,000 ha of AF until 2027. Given the low adoption rate of farmers and the simulation results, which highlight a limited efficacy of the existing support measures, a considerable increase of monetary support must be recommended. The suggestions made by DeFAF to increase the annual support and fund 100 % of the establishment cost should be contemplated when designing future funding schemes. Additionally, the institutional barriers still present must be recognised and addressed to create a truly enabling environment supporting farmers in establishing AF systems. For this, consulting services must be extended and subsidised. AF must be recognised as a multifaceted land use type, which is primarily characterised by using trees and shrubs to create agroecological systems in which synergies are utilised. The German definition of AF is considered too restrictive to enable farmers to use AF practices to their full potential. The bureaucratic effort involved in registering agricultural land as AF makes AF much less attractive than other environmental measures. Lastly and most importantly, legal security must be guaranteed in every stage of an AF systems lifecycle. Farmers must be able to establish, manage and harvest/remove AF systems without violating nature conservation requirements. This is to be guaranteed even when the system, which is primarily used for economic purposes, has taken the form of a protected biotope. This will ultimately also benefit the local ecology since more AF system will be established if legal security is guaranteed, which leads to the creation of more habitat and a more diverse agricultural landscape.

Further studies should expand the model presented in this thesis to include the potentially relevant factors, which are, as previously mentioned, currently missing. Including socio-ecological benefits and risks associated with climate variability would provide a more comprehensive picture of the AF system itself and a robust foundation of argumentation for policy revision. Additionally, it is recommended to use the methodology outlined in this thesis to test the adequacy of funding measures using various representative AF systems as the basis. This will highlight which AF system types are favoured by the present funding schemes. Additionally, it allows for the elaboration on how the funding contributes to national targets regarding climate change mitigation and adaptation as well as the halt of biodiversity loss.

In conclusion, while this thesis has identified potential economic benefits associated with the implementation of apple trees for table apple production into an arable farming operation, the true decision outcome is highly uncertain. The potential for the arable system to outperform the AF system indicates an existent risk, which must be considered. An enhancement of the present decision-model to be used in the support of policy makers can play a crucial role in promoting the sustainable integration of AF system into German agriculture.

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Annex

Annex I: Tree and shrub species that, according to Annex 1 of the GAPDZV, may not be planted in agroforestry systems (so-called negative list)

Scientific name	English name
Acer negundo	Box elder
Buddleja davidii	Butterfly bush
Fraxinus pennsylvanica	Green ash/Red ash
Paulownia tomentosa	Empress tree
Prunus serotina	Black cherry
Quercus rubra	Red oak
Rhus typhina	Staghorn sumac
Robinia pseudoacacia	Black locust
Rosa rugosa	Beach rose
Symphoricarpos albus	Common snowberry

Annex II: GAK Funding Area 2: Support for Agricultural Enterprises

To clarify whether investment support for AF systems is possible via the AFP, 8 of the responsible ministries of the Länder were contacted. Priority was given to the ministries of the respective Länder that do not offer area-based investment support for AF systems through the Funding Area 4 of the GAK. Six of the contacted ministries replied and provided varying levels of information on why AF systems are *not* funded via the AFP.

- Hesse:
  AF has not been integrated into the specific regulation of the Land. This is justified by the fact that the content of the AFP and the design of the IT systems used for it are fully implemented as a "non-IACS"-measure and are also categorised as such in the CAP Strategic Plan (HMLU, personal communication, 5. April 2024). IACS referres to the Integrated Administration and Control System, which serves for EU countries to control all area-based CAP-interventions (direct payments, rural development interventions) (EUROPEAN COMMISSION, 2024). Support for the establishment of new AF systems can only be implemented in accordance with the requirements of EU Regulation 2021/2116 if an IACS is implemented to carry out administrative control, in particular with regard to the exclusion of double funding on agricultural parcels (HMLU, personal communication, 5. April 2024). For this reason, funding for the establishment of AF system could only be implemented via an area-based funding programme linked to and controlled by the IACS. Such funding measure is not available in Hesse.
- Schleswig-Holstein:

The funding of AF through both GAK Funding Areas has been discussed and the introduction of an investment support measure cannot be ruled out. However, due to a "tight budget" for the funding period of 2023–2027, it was decided to exclusively fund the construction of animal welfare-promoting stables through GAK-/AFP-resources (MLLEV, personal communication, 3. April 2024).

- Brandenburg/Berlin:
  It is acknowledged that the CAP SP states that the establishment of AF systems may be funded via resources allocated to the AFP. However, Brandenburg/Berlin will introduce its specific investment support measure through Funding Area 4 of the GAK rather than Funding Area 2 (MLUK, personal communication, 3. April 2024). This aligns with the procedure of Bavaria and Mecklenburg-Western Pomerania. Brandenburg/Berlin will therefore be the third funding region, adopting this investment support measure.
- Saarland:
  In response to the initial enquiry as to whether the establishment of AF system can be subsidised via the AFP in Saarland, the only information provided was that the AFP is not offered in Saarland (MUKMAV, personal communication, 27. March 2024). This directly contradicts the information on the ministry's website (see: MUKMAV, 2019). The translated wording reads: "Agricultural investment support will also be continued in the 2023–2027 funding period.". Upon further enquiry, it was supplementarily explained, that in Saarland the transition into the new funding period is still ongoing. This is because the MUKMAV has been able to "work with funds and rules from the old funding period up to now". It has been acknowledged, that AF is considered as fundable through the AFP but it was added, that the decision on the choice of funding priorities is at the discretion of the Länder. In addition, it was pointed out that no concrete requests for the funding of the establishment of an AF system have yet been made in Saarland (MUKMAV, personal communication, 8. April 2024).
- Saxony-Anhalt:
  The MWL (Personal communication, 10. April 2024), points out that area-related funding is located in Funding area 2, while Funding area 4 contains the agricultural investment support measure. Furthermore, AF was only mentioned in the CAP SP as fundable via the AFP "but not explicitly included". The MWL therefore sees the compatibility of the GAK and the CAP SP at risk, which would mean, that EU funds could not be accessed, when funding investments over the AFP, which are usually regarded as area based. Although not as thoroughly explained, the reasoning is in line with that of the Hessian Ministry. Furthermore, it was pointed out, that previous experiences with SRC plantations have been negative, showing only little interest in

the funding of such measures. The question was raised, if therefore the administrative effort of implementing an AF funding measure would be justified (MWL, personal communication, 10. April 2024).

- Rhineland-Palatinate:
  It is not acknowledged that the establishment of AF systems may be funded via the AFP nor was an explanation provided on why it was chosen not to fund AF systems that way (DLR-RLP, personal communication, 27. March 2024). Upon further request, no response has been received until the submission of this thesis (30.04.2024).

Annex III: Point system in Lower Saxony's AF establishment support measure (Annex 2, RL AFS-Erl)

The table contains information on how many points are assigned to an AF management concept, based on certain criteria.

Criteria	**Category**	Points (1–5)
Cultivation system	Alley cropping	5
	Scattered trees	1
Type of usage	Energy wood (SRC)	3
	Fruit	1
	Food (not solely fruit, at least additionally nuts such as chestnut or walnut)	5
	Timber (harvest = 10 years)	5
	SRC combined with food and/or timber production	5
Plot size	< 2ha	1
	2–10 ha	5
	> 10 ha	3
Percentage of wooded area	< 2 %	1
	2–10 %	3
	11–20 %	3
	21–35 %	2
	> 35 %	1
Region	North (Emden, Wilhelmshaven, districts of Aurich, Wittmund, Friesland, Wesermarsch, Cuxhaven, Stade)	2

	North-west (Districts of Leer, Emsland, Grafschaft Bentheim)	3
	North-east (Districts of Lüneburg, Lüchow-Dannenberg, Uelzen)	2
	Süden (Districts of Hildesheim, Hameln-Pyrmont, Holzminden, Northeim, Göttingen, Goslar)	3

Annex IV: Institutional barriers to the adoption of AF in Germany pre-2023

- Obstacle 1: AF systems are not recognised as a formal land use unit.

Before 2023, AF systems had no official legal definition within German law. The combination of arable agriculture, pasture and woody perennials was therefore legally not considered as one system, which could be registered as one plot. Instead, these types of land use had to be registered as separate plots, which meant, that a min. required size of 0.3 ha per plot had to be reached for woody perennials to be considered a separate plot of permanent crops. Furthermore, spatially separate rows or areas of trees could not be registered as the same plot of land if no physical connection between the rows existed. This meant, that in order to establish an AF system with distinct rows of trees within a field, these rows had to be min. 0.3 ha each. AF systems with a minimal number of separate plots had therefore to exhibit a “comb-structure” with all tree rows within the field being connected by a tree row on the field edge. The separate registration of each plot included providing information about the woody crop that was to be established. This meant a significant bureaucratic expense only to keep the agricultural status of the area, without any additional benefits in term of funding. An exception was and still is the establishment of plots of permanent crops under certified organic cultivation, since this was and still is accompanied by an extra payment of 1,450 €/ha (BMEL, 2024, p. 1260). If plots/rows of trees were not registered as separate plots they could be considered as protected landscape features. This is still the case, when established AF systems do not comply with the requirements defined in § 4 GAPDZV or if they are not registered as AF systems (BMEL, 2024, p. 515).

The introduction of the legal definition in 2023 made this above-described work-around obsolete. Now, trees in fields can be registered as AF systems, but the associated requirements are considered to be an institutional barrier in themselves. The respective article in the GAPDZV notes that certain species of woody perennials must not be included in eligible AF systems. This restriction of usable tree species is what AF stakeholders have criticised, since the negative list contains at least 1 species, which is regarded as a valuable addition to AF systems, black locust (*Robinia pseudoacacia*). This north-american, nitrogen-fixing and fast-growing tree species thrives in drier areas of Germany (e.g. central and eastern Germany) as well as in riparian systems. Its ability to grow rapidly in dry and nutrient poor soils as well as its tendency to spread via root suckers, led to its classification as an invasive species by German nature conservation authorities (NEHRING ET AL., 2013). Systems established after 01.01.2022 containing black locust, can therefore not be legally registered as AF.

The rules, contained in Eco Scheme 3, which is a funding measure in Pillar I of the present CAP, are considered to be too strict BÖHM ET AL., (2023). Especially mandatory spacings between tree rows and between tree rows and the field edge are regarded as limiting what is considered to be one of AFs strengths, its inherent adjustability to site specific conditions.

- Obstacle 2: min. size for separate plots is too large.

This obstacle ties directly into obstacle 1 and is to be considered obsolete or at least only of significance because of the possibility to receive greater funding for permanent crop areas under organic cultivation than for wooded area in AF systems. By raising the funding for AF, this obstacle would be completely removed.

- Obstacle 3: restrictions concerning rotation length and choice of woody species.

This obstacle was especially relevant since most modern AF systems in Germany are SRC systems. The requirements for SRC plantations have not changed significantly after the latest CAP reform, with the exception that, species listed in the negative list must also not be planted in SRC plantations. A limited positive list of approved species exists for SRC systems, which contains fast growing genera such as willow (*Salix*), poplar (*Populus*), birch (*Betula*), and alder (*Alnus*). The required max. rotation length is 20 years (i.e. the wooded area is to be cut down at least once every 20 years) (BMEL, 2024, p. 522). Farmers, choosing to register the wooded area as SRC were and still are prevented from establishing systems diverse in structure, containing not only the few approved fast-growing species but also high-value timber species with much longer rotation lengths. The new CAP allows for the combination of different species and production goals within the same AF system, if no species from the negative list are used and the design meets the requirements of either § 4 GAPDZV or ES 3. This is only the case when the system is registered as AF, not as SRC. With regards to an additional funding, a further restriction concerning the choice of planting material has been added post 2023. Certain investment support schemes for the establishment of AF systems require that only certified planting material is used, when choosing species falling under the Forest Reproductive Material Act

(FoVG). Thereby, limitations regarding species and planting material, used for AF systems can still be regarded as an existing institutional barrier, even post 2023.

- Obstacle 4: AF systems in riparian zones require special permission.

Since no legal definition of AF existed pre 2023, this obstacle affects trees in riparian zones in general. Germanys Water Resources Act (WHG) states in §38, (4), 2. that native tree and shrub must not be removed in riparian areas except for when done within the framework of appropriate forestry. Additionally, no non-native trees and shrubs are to be planted in these areas. This leads on the one hand to the conservation of remaining riparian systems but prevents farmers managing fields in riparian areas to plant trees, since this would be accompanied by the change of land status to either forestry or the trees would be considered a protected landscape feature. The establishment of AF systems in riparian zones was thereby only possible with a special permission from the respective authorities. The ecological benefits of establishing riparian buffers are an argument for allowing the propagation of even nonnative trees and shrubs when the baseline scenario (grassland or arable land with buffer-zone in which no pesticide use is permitted) indicates e.g. an influence of fertilisers and or pesticides on the aquatic ecology. Since the latest CAP reform, specific distancing rules for tree rows have been introduced, especially if the maintenance of AF systems is to be funded via ES 3. These rules stipulate that a min. distance of 20 m must be maintained between the tree strips and the edge of the field, with the exception for AF systems near running waters. Attachment 5 Nr. 3.2.6 of the GAPDZV states, that if a wooded strip is planted alongside a watercourse or near a watercourse, the distance to the edge of the area may be less than 20 m. The precise distance is not explicitly specified and should therefore be determined in consultation with the relevant authorities on a case-by-case basis.

- Obstacle 5: AF system are not recognized as a measure for rural development in Pillar II of the CAP.

Even though, the establishment of AF systems is considered to be eligible for funding by the EU since 2005 (see: Council regulation (EC) No 1698/2005, Article 44), MS have to explicitly integrate measures which are to be funded nationally into their national CAP. Up until 2023, Germany did not include AF systems into their Pillar II funding system. Pillar II of the CAP contains environment- and rural development- oriented measures such as the AECMs, which are supposed to promote agricultural practices that are in line with EU objectives. MS can choose to integrate measures, suggested by the EU into their national programmes. In Germany even post 2023, only few of the Länder offer a support scheme for AF (see: 2.3.2.). EU Regulation 2021/2115 suggest an investment support of up to 100 % of total investment cost. No federal state has introduced a measure of this scale. An inadequate financial support for the establishment as well as the management of AF systems must still be regarded as a major institutional barrier.

- Obstacle 6: AF systems are not considered within the “Joint Task for the “Improvement of Agricultural Structures and Coastal Protection””.

The joint task, known as the GAK, is considered to be the most important national funding instrument for the support of agriculture and forestry, rural development and improvements in coastal protection. For detailed information, see 2.3.2.1.1. It contains a multitude of measures, which are, when implemented into Pillar II funding via the federal states, co-financed by the German government. Pre 2023, AF was not considered within this programme, making it a financially less attractive measure for federal states to implement, since no co-financing would have been possible. The ecological role of trees, hedges and other wooded structures in agricultural landscapes was recognised and the establishment of such elements encouraged as the integration of natural structural element in fields. Such elements must not be removed, which makes their establishment less attractive for farmers. In the current version of the GAK, AF is explicitly mentioned as a measure to be integrated as an AECM via the federal states as Pillar II funding. There it is suggested that the establishment of AF systems is funded with up to 65 % of eligible cost.

- Obstacle 7: AF systems are not considered ecological priority areas.

The old CAP included “Greening” as a central part of promoting environmentally friendly agriculture. To be eligible for the “basic premium”, i.e. area-based direct payments, farmers had to comply with Greening standards. This included maintaining a certain amount of ecological priority area which had to make up 5 % of the eligible arable area. This could have been specific leguminous crop species, cover crops, landscape features or SRC plantations. Depending on the type of registered ecological priority area, the area got multiplied with a weighting factor, ranging from 0.3–2. Woody landscape features such as hedgerows and SCR plantations received weighting factors of 2 and 0.5, respectively. Annex X of the Delegate Regulation 639/2014 suggests that AF system can be considered ecological priority areas with a weighting factor of 1. In the respective German regulation (DirektZahlDurchfV[18]), AF was not considered an ecological priority area. Post 2023, “Greening”, was replaced by the extended conditionality. A mandatory maintenance of 7 % of “unproductive land” replaced the ecological priority areas. AF is explicitly not regarded as such, since it is a productive, agricultural system.

- Obstacle 8: Min. investment sum for support is too high.

[18]Direct Payments Implementation Regulation (DirektZahlDurchfV) of November 3, 2014 (Federal Law Gazette I p. 1690), last amended by Article 1 of the Regulation of November 3, 2022 (Federal Law Gazette I p. 1974).

The establishment of specific types of tree-based agricultural systems, which fall under the broader definition of AF, were funded, even before an explicit AF funding was introduced in 2023. Such systems include traditional meadow orchards or SRC plantations. As the establishment of meadow orchards is usually associated with nature conservation as the primary goal, a multitude of requirements are to be met in order to receive any funding. The establishment of SRC plantations was funded pre-2023, e.g. in Brandenburg, where 40 % of the establishment costs were subsidised. The min. investment sum of 7,500 € was considered too high in the context of AF systems. The few investment support schemes, which exist today require either no min. investment sum or an investment sum of 2,500 € (except for Saxony, which requires 20,000 €, see 2.3.2.5.).

- Obstacle 9: Establishment of AF system on permanent pasture requires special permission.

Since 2013, the maintenance of permanent pasture has been one of the central “Greening” requirements of the CAP. The planting of trees on pasture, e.g. to establish silvopastoral AF systems, is usually regarded as a conversion of permanent grassland into permanent crops. Therefore this “conversion” required a special permission, which included the conversion of another part of land into permanent pasture, to compensate for the initial intervention. After the latest CAP reform in 2023, the planting of trees on permanent pasture is explicitly permitted and does not count as a conversion of permanent pasture into another land use type.

- Obstacle 10: Restriction of eligible AF systems to single-tree systems.

Article 23, paragraph 2 of the EU regulation 1305/2013 states that agroforestry systems are land-use systems in which an area is covered with trees and at the same time used for agriculture. The min. and max. number of trees per ha shall be determined by MS, considering local soil, climatic and environmental conditions, forest tree species and the need to ensure the sustainable agricultural use of the land. HÜBNER ET AL. (2020) seem to interpret this as a restriction to systems that resemble traditional AF systems such as the Central European meadow orchards or the Mediterranean forest-pasture systems (Montado/Dehesa). What the article explicitly states that only trees and not other woody perennials such as shrubs are considered to be a characteristic of AF systems. AF stakeholders around the world consider AF to be simply the integration of woody vegetation into agricultural systems, irrespective of their placement in the context of the field. The more specific the definition in a regulation is, the fewer ways are available to those affected by the regulation to achieve the objective that is to be promoted. Post 2023, the German AF definitions for maintaining agricultural status of a field and even more so to receive an area based additional payment, leave little room for interpretation (see 2.3.1.). The most restrictive are certain investment funding schemes on federal state level, which only support the establishment of silvoarable alleycropping systems, excluding systems on grassland and/or systems with trees scattered over the field. The institutional barrier of restricting how an AF system is to be designed, is still present today and a compromise between over- and under restricting design choices must be found.

- Obstacle 11: AF is not recognised as a measure of erosion reduction.

In Germany, a regular categorisation of agricultural fields is being made by federal state authorities, regarding the field's susceptibility to wind- and or water erosion. Depending on what category of erosion risk a field falls under, certain standards must be met by the farmer in order to comply with the respective regulation. E.g., fields which fall under the category "$K_{Wasser1}$" (meaning susceptibility to water erosion class 1), must not be ploughed between 01.12 and 15.02. Fields that fall under the category "$K_{Wasser2}$", must neither be ploughed the rest of the year, if no immediate sowing follows. Additionally, "$K_{Wasser2}$"-fields must never be ploughed before the cultivation of crops grown with a distance between the rows over 45 cm, such as maize, sugar beet and potato. "K_{Wind}"-fields (fields classified as susceptible to wind erosion), must not be ploughed after 01.03. if no immediate sowing follows. Additionally ploughing is entirely prohibited before the cultivation of the above-described row crops (e.g. maize, sugar beet, potato) (BMEL, 2024, p. 509). Before 2023, AF was not officially acknowledged as a measure of reducing erosion. On the other hand, it was suggested to establish erosion control strips parallel to the slope, such as grass strips of specific dimensions (see e.g. the Bavarian Erosion Protection Regulation, ESchV[19], as one example for a federal state specific regulation on erosion control). After the 2023 CAP reform, AF is explicitly mentioned as a measure to remove the status "at risk for erosion", i.e. "K_{Wasser}" or "K_{Wind}". This means that the strict rules for reducing soil erosion no longer apply after establishing an AF system on fields previously at risk for erosion (BMEL, 2024, p. 509). This institutional barrier can therefore be considered obsolete.

- Obstacle 12: Restricted max. number of trees on agricultural fields set by EAFRD regulations

As per EU regulation 1305/2013, MS are granted the authority to determine the number of min. and max. number of trees (min. and max. number) that distinguish AF systems from other agricultural land use types such as arable land or pasture. Since before 2023 no standardised definition of AF existed within German regulations, HÜBNER ET AL. (2020) draw conclusions from other regulations which deal with trees on agricultural land. The

[19]Erosion Protection Regulation (ESchV) of November 26, 2015 (GVBl. p. 442, BayRS 7841-3-L), as amended by the Regulation of April 27, 2023 (GVBl. p. 195).

authors therefore refer to the InVeKoSV[20], which outlines the procedures and requirements for implementing support measures in the context of agricultural policies among other things. § 19, (3), InVeKosV refers to Article 9, EU Regulation 640/2014[21], which states that agricultural land eligible for direct payments may not have more than 100 trees/ha. This regulation does not refer to AF systems specifically but neither explicitly exempts them from this rule. If this 100 tree/ha-rule would apply to AF systems, it would severely limit the design options, farmers could choose from. However, the AF definition introduced into German legislation in 2023 does go beyond the 100 tree-rule. It states that AF systems must either consists of an agricultural field of any kind (arable, grassland, permanent crop) combined with either 50–200 trees/ha or with min. 2 wooded rows, which in total make up max. 40 % of the total area of the AF system (§4, (2), GAPDZV).

- Obstacle 13: AF not recognised as a production-integrated compensatory measure.

The Federal Nature Conservation Act BNatSchG states in § 13 (et seq.), that unavoidable interventions in nature must be compensated. Such unavoidable interventions often are carried out in agricultural locations, e.g. conversion of agricultural land into land for new housing estate. These interventions can be compensated by ecologically improving agricultural areas, by e.g. extensification of grassland management, planting meadow orchards, hedges etc. The BNatSchG mandates that consideration be given to agricultural concerns when selecting compensation areas and measures. Measures, which combine an ecological improvement with the maintenance of agricultural production, are to be favoured over measures, that lead to taking agricultural land out of use entirely (§ 15, (3) BNatSchG). The production-integrated compensation of interventions in nature are not a subsidy measure and are therefore independent of subsidy policies and funds. Farmers can implement these compensatory measures either for third parties or for their own interventions (e.g. building of a barn). The area remains under agricultural management and is therefore still eligible for direct payments (BÄRWOLFF, 2014). HÜBNER ET AL. (2020) state, that AF is not regarded as a production integrated compensatory measure yet but should be recognised as such. On level of the federal states however, there have been suggestions to consider SRC plantations as well as AF systems, consisting of strips of SRC to be considered as production-integrated compensatory measures. In Thuringia, the suggested measures were coordinated with the upper and highest nature conservation authorities, which are also responsible for the approval of procedures according to the

[20]The Regulation on the implementation of support measures and the integrated administration and control system (InVeKoSV), Regulation of February 24, 2015 (Federal Law Gazette I p. 166), as last amended by Article 2 Paragraph 6 of the Law of December 4, 2023 (Federal Law Gazette 2023 I No. 344).

[21]Commission Delegated Regulation (EU) No 640/2014 of 11 March 2014 supplementing Regulation (EU) No 1306/2013 of the European Parliament and of the Council with regard to the integrated administration and control system and conditions for refusal or withdrawal of payments and administrative penalties applicable to direct payments, rural development support and cross compliance

compensation regulation (GÖDEKE ET AL., 2014). In 2017, the planting of an AF system with high value timber trees on extensively managed grassland was indeed recognised as a production-integrated compensatory measure in Thuringia (see: LANDESHAUPTSTADT ERFURT, STADTVERWALTUNG, 2017). Depending on federal state specific regulations, only very specific types of AF are considered as compensatory measures. The BayKompV[22], which is the regional regulation on the compensation of interventions in nature and landscape in Bavaria, includes the establishment of meadow orchards as well as SRC plantations. However, these have to meet specific advanced standards to be considered compensatory measures (MÜLLER-PFANNENSTIEL ET AL., 2014).

In 2020 the Federal Compensation Regulation (BKompV[23]) has been introduced. It specifies the legally prescribed conversion-related intervention regulation from the BNatSchG. In doing so it “harmonises the application” of said regulation across the Länder (BMEL, 2020). As of 2024, it does not explicitly include “AF systems” as a measure of compensation, although e.g. the establishment of traditional meadow orchards is listed. As the compensatory measures are not related to the CAP but are administered via nature conservation law, the CAP reform is not expected to directly change the above-described situation. However, it should be noted that, in order for a change in agricultural practice to be rated as a compensatory measure, no other public funding (e.g. Pillar II investment support) must be utilised for this change (§ 16, (1), 3. BNatSchG). This means, that if the establishment of an AF system was to be considered a compensatory measure in individual cases, the respective farmer might want to evaluate, which option in the financially better one.

- Obstacle 14: Subsidies for biomass production in AF through Renewable Energy Law inadequate.

The Renewable Energy Law (EEG[24]) in Germany is aimed at promoting the generation of electricity from renewable sources such as wind, solar, and biomass by providing financial incentives to renewable energy producers. The goal is fostering the transition towards a more sustainable and environmentally friendly energy system. HÜBNER ET AL. (2020) criticise, that the establishment and management of AF systems with the primary goal of biomass production are not included nor funded in this law. The newest version of this renewable energy law does not mention AF or SRC.

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[22]The Bavarian Compensation Regulation (BayKompV) of August 7, 2013 (Law and Regulation Gazette. p. 517, BayRS 791-1-4-U), as amended by Section 2 of the Law of June 23, 2021 (Law and Regulation Gazette p. 352).
[23]The Federal Compensation Regulation (BKompV) of May 14, 2020 (Federal Law Gazette I p. 1088)
[24]The Renewable Energy Sources Act (EEG) of July 21, 2014 (BGBl. I p. 1066), last amended by Article 1 of the Law of February 5, 2024 (BGBl. 2024 I No. 33)

- Obstacle 15: Prohibition of planting trees/shrubs in flood-prone areas.

The planting of shrubs and or trees is prohibited in §78, (1), 6., if the objectives of precautionary flood protection are thereby contradicted. HÜBNER ET AL. (2020) regard this as an unnecessary limitation on the establishment opportunities for AF systems and suggest to explicitly encourage the establishment of AF systems, where water retention and flood mitigation can thereby improve. This institutional barrier is again independent of CAP regulations and is set via national law. Nonetheless, "water retention in the landscape" is a fundable AECM (Pillar II funding) in the new CAP. Brandenburg, for example, offers this measure and rewards the retention of water with 261 €/ha on arable land and 344 €/ha on permanent pasture. AF is not mentioned as a measure for water retention, while only engineering techniques such as the sealing of drainage channels are mentioned. However, the planting of trees is not explicitly prohibited (MLUK, 2023). As the effect of woody perennial plants on flood-causing factors (interception, infiltration) is increasingly better examined (see e.g. MARAPARA ET AL., 2021), it seems appropriate to realise and utilise the regulating effect of specific land use types on local hydrological factors.

- Obstacle 16: Prohibition on the use of existing woody perennials.

HÜBNER ET AL. (2020) note, that depending on the specific regulations on district level, different rules apply regarding how existing trees and hedges have to be dealt with. In their example from the Tree Protection Regulation of the Elbe-Elster district in Brandenburg (GehölzSchVO EE[25]) hedges over a certain size must not be removed or significantly changed in their structure. On this basis, the authors argue, that coppicing a hedge entirely to use its biomass is prohibited, even though, this practice is considered a traditional method of maintaining and rejuvenating hedges. The GehölzSchVO mandates the maintenance of hedges in § 3, not specifying which methods are appropriate. The use of hedge trimmings is not addressed. After the latest CAP-reform, hedges as well as other woody perennial structures in agricultural landscapes which do not at least comply with the definition of AF in §4 GAPDZV are either protected by the district level regulations or considered landscape features by CAP-specific regulations and are therefore still excluded from use.

- Obstacle 17: Potential conflicts regarding the use of pesticides in and around AF systems.

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[25]Regulation of the District of Elbe-Elster for the Protection of Trees and Hedges (Tree Protection Regulation - GehölzSchVO EE) of February 12, 2013 (published in the Official Gazette for the District of Elbe-Elster, Issue No. 3 of February 27, 2013).

Municipalities are assessed regarding their share of landscape defining structures, such as field margins, hedges, copses etc. If a municipality is classified as deficient in such structured, stricter rules on the use of pesticides in fields adjacent to these structures are employed. Specific drift-reducing technology must be used to spray crops. Additionally, 5 m distance must be kept to the structures. Explicitly excluded from this rule are structures, which are legally still classified as agricultural land. That's why HÜBNER ET AL. (2020) regard this rule not as an institutional barrier per se but rather mention the overall low acceptance of woody structures such as hedges and copses on the part of farmers as problematic. It is therefore to be explicitly communicated, that AF systems are regarded as agricultural fields after the 2023 CAP-reform and that no further restriction on the use of pesticides other than what is regarded as good agricultural practice is being placed onto farmers managing AF systems.

- Obstacle 18: AF systems are classified as protected landscape features.

As discussed above, trees in agriculture were and still are regarded as structures with a solely ecological value, if these trees are not explicitly established in the form of AF systems, SRC plantations or permanent crops. The new CAP makes it possible to legally harvest trees from AF systems, if they meet the requirements.

- Obstacle 19: Lack of guidelines considering AF in spatial planning.

HÜBNER ET AL. (2020) pledge for the consideration of the beneficial effects the implementation of AF systems on landscape level can have in the spatial planning instruments. The authors also state, that although certain federal states recognise and communicate the beneficial effect of woody structures such as SRC plantations (e.g. Saxony[26]) the published recommendations remain largely ineffective. In the future, AF should be considered in the various spatial development plans. The term "Agroforestry" should be used explicitly, also to clearly distinguish them from extensive SRC plantations. Possible synergies of establishing AF areas to fulfil the obligation for habitat connectivity at a regional level should be further pursued and positively emphasised.

- Obstacle 20: Differing specifications within the neighbourhood laws.

Since before 2023, there have been no specific distancing rules for the woody components of AF systems to neighbouring fields, the neighbourhood law, which can differ depending on the federal state was used to determine the distance of trees to the field edged. In Brandenburg, this min. distance of trees to the edge of a field, managed by another farmer is 8 m (§37, (1), BbgNRG[27]). Other federal states may have different rules. HÜBNER ET AL.

[26]State Development Plan 2013, dated August 14, 2013 (SächsGVBl. p. 582)
[27]Brandenburg Neighbor Law (BbgNRG) § 37, (1) - Distances from Borders for Trees, Shrubs, and Hedges.

(2020) suggest implementing explicit rules for trees planted as AF systems. With the 2023 CAP-reform, a uniform distancing-rule for trees in AF systems has been established into the German legislation, which makes this institutional barrier obsolete. The distancing rules are now considered to be too strict (see Obstacle 4) and present therefore a new institutional barrier.

Annex V: List of consulted experts

Name	Topic of expertise	Calibration
Jan Große-Kleimann	AF, practical farming	No
Burkhard Kayser	AF planning, tree crops	Yes
Michael Grolm	Apple tree management	No
Daniel Hermann	Investment economics	No
Carlo Marzini	Funding application	No
Lena Voßkuhl	AF establishment, management	No
Michael Müller	AF establishment, management	No
Marina Klimke	Environmental Law	No
Klaus Krohme	Apple production	No
Michael Blanke	Apple production	No
Hubert Hüging	Arable agriculture	No

Annex VI: Personal Declaration

I hereby affirm that I have prepared the present thesis self-dependently, and without the use of any other tools, than the ones indicated. All parts of the text, having been taken over verbatim or analogously from published or not published scripts, are indicated as such. The thesis has not yet been submitted in the same or similar form, or in extracts within the context of another examination.

Bonn, 02.05.2024

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Student’s signature