Earth System Governance 22 (2024) 100223

Contents lists available at ScienceDirect

Earth System Governance

journal homepage: www.sciencedirect.com/journal/earth-system-governance

Allowing for the multifunctionality of agroforestry systems – lessons from a legal perspective with a focus on Germany

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ARTICLE INFO

Keywords:
Legal barriers
Agroforestry
Multifunctionality
Common agricultural policy
Nature conservation law
Social-ecological system

ABSTRACT

In view of the multiple challenges faced by agriculture, agroforestry can promote multifunctional farming landscapes. While the law is a decisive factor for the adoption of agroforestry, it is not as yet comprehensively addressed in agroforestry and governance research. We operationalize Ostrom's social-ecological systems framework to analyze agri-environmental laws at EU, German federal and state level using doctrinal and non-doctrinal legal research methods. We show that current legal provisions disincentivize farmers to establish agroforestry systems and do not adequately address the benefits and risks of agroforestry systems for ecosystem functions and services and thus overall multifunctionality. We identify terminological misconceptions on the term 'agroforestry', contradictions between subsidy law and command-and-control law, and a lack of tailored steering towards multifunctionality as major legal barriers to the promotion of agroforestry. Therefore, the example of agroforestry illustrates the challenge inherent in reconciling agricultural and environmental targets in agri-environmental law.

1. Introduction

Agriculture is a key driver for biodiversity decline and climate change (IPBES, 2019; IPCC, 2022). At the same time, it has shaped today's landscapes and contributed to the diversity of terrestrial ecosystems (Plieninger et al., 2006). To this end, agroecological approaches such as agroforestry that allow for the multifunctionality of landscapes and understand humans as an integral part of the environment (Kremen and Merenlender, 2018) are a possible building block from which to reconcile environmental, agricultural and societal targets. Such an integrated management approach is a key objective of the Convention on Biological Diversity (CBD, 1992, 2000). While this integrated management approach was emphasized again in the 2023 Kunming Montreal Global Biodiversity Framework (CBD, 2022), it has barely been implemented in the governance of ecosystems at the national level (Prip, 2018).

The European Union (EU) is a key example of the challenge of transforming the governance of agroecosystems (Kozar et al., 2023). The Common Agricultural Policy of the European Union (CAP) is the key instrument for the governance of agroecosystems (Pe'er et al., 2014). However, the CAP is criticized for subsidizing European agriculture through subsidies paid per hectare of a farm ('direct payments') with only little environmental requirements (Pe'er et al., 2020; Mupepele et al., 2021a). The latest revision of the CAP came into force in 2023. While it introduced several new elements to promote environmentally-friendly farming practices, the CAP's focus remains on area-based payments (Pe'er et al., 2020). Additionally, no comprehensive European agricultural law exists (Mupepele et al., 2021a). Therefore, the relationship between agriculture and the environment remains largely unaddressed in European agri-evironmental law (Mupepele et al., 2021a).

Agroforestry describes "the practice of deliberately integrating woody vegetation (trees or shrubs) with crop and/or animal systems to benefit from the resulting ecological and economic interactions" (Burgess and Rosati, 2018, p. 803). It is an example of an agroecological approach that has the potential to integrate environmental protection into land use systems and thus creates "win-win opportunities" (Plieninger, 2011, p. 437). Moreover, it contributes to multifunctionality by providing multiple ecosystem functions and services (Veldkamp et al., 2023). However, agricultural intensification and subsidies for the removal of trees led to the decline of traditional agroforestry systems such as orchard meadows (Eichhorn et al., 2006;

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https://doi.org/10.1016/j.esg.2024.100223
Received 3 January 2024; Received in revised form 3 July 2024; Accepted 9 September 2024
Available online 19 September 2024

Nerlich et al., 2013).

While European policies such as the European Forest Strategy call for the promotion of agroforestry (European Commission, 2021), legal and administrative requirements currently disincentivize the management and establishment of agroforestry systems in Europe (Mosquera-Losada et al., 2018; Tsonkova et al., 2018; Litschel et al., 2023). For example, areas under agroforestry struggle to receive funding under the CAP and existing funding schemes at the EU level are often not implemented by the member states (Mosquera-Losada et al., 2018; Tsonkova et al., 2018). Moreover, protection of agroforestry systems under nature conservation law (Tsonkova et al., 2018) and high administrative burdens for the application of subsidies and permits for agroforestry compared to conventional agriculture (García de Jalón et al., 2018) can prevent farmers from establishing or managing agroforestry systems.

Germany is an example of a country with a rich tradition in agroforestry but a low prevalence of agroforestry in contemporary farming systems (Nerlich et al., 2013; Den Herder et al., 2017). While the criticism of the lack of subsidies for agroforestry in Germany (Böhm et al., 2017) was addressed in the last CAP revision, bureaucratic hurdles, a lack of funding, limited duration of land tenure and barriers to the management of agroforestry systems by command-and-control law hinder the establishment of agroforestry systems (Tsonkova et al., 2018; Litschel et al., 2023). On the other hand, German nature conservation law is also criticized for granting privileges to agriculture and not sufficiently specifying rules for the protection of woody landscape features (Köck, 2019). In contrast to the perspective of nature conservation law as a barrier to the management of woody vegetation by farmers (Tsonkova et al., 2018), this criticism would require strengthening nature conservation law and prohibiting the active management of woody vegetation by farmers (Köck, 2019). Moreover, while agroforestry systems can provide many ecosystem functions and services and thus contribute to multifunctionality (Veldkamp et al., 2023), their effects are dependent on the land use context and the type of agroforestry system in question (Eichhorn et al., 2006; Torralba et al., 2016; Mupepele et al., 2021b). Importantly, trade-offs may arise between the management intensity of agroforestry systems and their environmental benefits (Eichhorn et al., 2006, p. 46). Therefore, agroforestry is a prime example for the need to take an interdisciplinary perspective on the legal framework that takes into account the multiple interactions between social, ecological and legal drivers (Martin and Ruhl, 2023) and considers the potentials and risks of agroforestry systems for the provision of multiple ecosystem functions and services.

However, such a systems perspective is so far seldomly taken by legal scholars (Martin and Ruhl, 2023, p. 157) who most often focus on doctrinal legal research (Du Plessis, 2023, p. 21–22). Moreover, most existing studies by legal scholars analyze the interplay between the law, adaptive management and the resilience of social-ecological systems from a meta-perspective (Frohlich et al., 2018; Bohman, 2021), but an application of a systems approach to legal sciences in a concrete legal case study remains scarce. Likewise, with some exceptions (Tsonkova et al., 2018; Klimke and Zengerling, 2024) few studies have analyzed the legal framework for agroforestry beyond the review of subsidies (Mosquera-Losada et al., 2018; Santiago-Freijanes et al., 2018).

In targeting these research gaps and taking Germany as a case study region, the aim of this paper is to analyze the extent to which provisions from agri-environmental law account for the multifunctionality of agroforestry systems by maximizing benefits and minimizing risks for the provision of multiple ecosystem functions and services. As this analysis requires knowledge on both the contribution of agroforestry to multifunctionality and of the applicability of current agri-environmental laws to agroforestry, our research aims to answer three consecutive research questions and thus complements analyses of agroforestry law from a strictly legal perspective (Böhm et al., 2017; Klimke and Zengerling, 2024):

1) What are the main benefits and risks of agroforestry systems for ecosystem functions and services that need to be considered in the legal analysis?
2) What are the principal provisions in subsidy law and command-and-control law at the EU, federal and state level that regulate agroforestry systems in Germany?
3) Building on the findings of (1) and (2), to what extent does the current legal framework enhance the benefits and minimize the risks of agroforestry systems for ecosystem functions and services and thus contribute to multifunctionality?

We draw on the social-ecological systems framework (SES framework, Ostrom, 2009; McGinnis and Ostrom, 2014) as an analytical framework and use a combination of doctrinal (i.e. the method of legal interpretation, Brugger, 1994) and non-doctrinal research methods (Martin and Ruhl, 2023) to analyze agroforestry-related law in Germany. We focus on orchard meadows, hedgerows, alley cropping systems (ACS) and grazed forests as four modern and traditional agroforestry systems to be found in Germany. We combine a literature review on the benefits and risks of these agroforestry systems for ecosystem functions and services with a review and legal interpretation of provisions in agri-environmental law to highlight current possibilities and constraints in law with regard to the multifunctionality of agroforestry systems. Since agroforestry practices are not always named as such in law (Santiago-Freijanes et al., 2018), we include the legal framework for woody landscape features in our analysis. To account for Germany's federalist structure, we give examples from state law and focus on the federal states of Brandenburg, Baden-Württemberg and Lower Saxony as three states with distinct agricultural structures. The scientific contribution of this article is thus twofold: Firstly, we operationalize the social-ecological systems framework for ecosystem-tailored legal research at the case study level. Secondly, in applying the SES framework, we identify whether and to what extent the main provisions in subsidy law and command-and-control law promote the multifunctionality of agroforestry systems by enhancing benefits and minimizing risks for the provisioning of multiple ecosystem functions and services.

2. Analytical framework

2.1. The social-ecological systems framework

Social-ecological systems (SES) research is an interdisciplinary field of study that addresses the interactions between society and the environment and their outcomes for normative goals such as 'sustainability' (Partelow, 2018, p. 2). In this context, a social-ecological system describes "an ecological system intricately linked with and affected by one or more social systems" (Anderies et al., 2004, p. 3). Different frameworks have been developed to analyze the interactions in SES (Binder et al., 2013). The social-ecological systems framework (SES framework, Ostrom, 2009; McGinnis and Ostrom, 2014) was selected as an analytical framework for this paper, as it has a focus on the role of institutions, as it clearly differentiates between the ecological, social and governance system and as it can be applied in a diagnostic procedure to the analysis of SES (Binder et al., 2013; Hinkel et al., 2015).

In the most recent version of the SES framework (McGinnis and Ostrom, 2014), it is differentiated between so-called 'first-tier variables': The resource system (RS) and the resource units (RU) constitute the ecological subsystem, and the actors (A) and the governance system (GS) constitute the social system. The focal action situation plays the central role in the SEF framework, as here "all the action takes place as inputs are transformed by the actions of multiple actors into outcomes" (McGinnis and Ostrom, 2014, p. 4). 'Second-tier variables', for example rules constituting the governance system, further characterize the first-tier variables (McGinnis and Ostrom, 2014). In the following, we apply the first-tier variables and selected second-tier variables of the SES

framework to agroforestry in Germany. Next, we describe our operationalization of the SES framework for the analysis of the legal framework for agroforestry in Germany. Due to the overarching nature of our research questions and the focus on legal research, we do not apply the SES framework to a single case study in a defined area, but proceed with applying the SES framework to the example of agroforestry at the federal level in Germany.

2.2. Application of the SES framework to agroforestry

Although the SES framework is widely applied in sustainability sciences, the second-tier variables proposed by Ostrom (2009) and McGinnis and Ostrom (2014) are interpreted heterogeneously, especially as there is no uniform method for their application (Hinkel et al., 2015; Partelow, 2018). By adopting the definitions for the first-tier variables proposed by McGinnis (2011), the attributes and indicators summarized by Partelow (2018) and previous applications of the SES framework to agroforestry (Guimarães et al., 2018; Torralba et al., 2018), the first- and second-tier variables of the SES framework can be applied to German agroforestry as follows (Table 1):

In the case of agroforestry, the different types of agroforestry systems to be found in Germany (e.g. orchard meadows, hedgerow systems, alley cropping systems, grazed forests) are examples for resource systems (RS, Fig. 1; Torralba et al., 2018). The components of the agroforestry systems (e.g. trees, shrubs, cattle, crops, grassland) are the resource units (RU, Guimarães et al., 2018; Torralba et al., 2018). The central actors are farmers (A). In a given focal action situation, they establish, manage and harvest (I1) the resource units. The SES framework initially had a focus on the delivery of concrete divisible units or products (e.g. number of fish) and the associated benefits and costs (McGinnis and Ostrom, 2014). However, McGinnis and Ostrom (2014) acknowledge that a resource unit can be understood more broadly and comprise also regulating services. Following this understanding and the interpretation by Guimarães et al. (2018), ecosystem functions and services provided by agroforestry (e.g. biomass production, erosion control) can also be understood as benefits provided to farmers. These benefits can be measured as part of the productivity of the resource system (second-tier variable RS 5). Next to farmers, farm advisors, land owners and private companies may advise, influence or fund the management of agroforestry systems by farmers. Likewise, other actors such as consumers and tourists may benefit directly or indirectly from agroforestry systems, for example through the provision of wood or meat products or recreation (Torralba et al., 2018).

The governance system comprises the institutions and rules that shape the behavior the actors in the SES (Table 2). The law is a central component of the governance system (Kotzé and Kim, 2019; Bohman, 2021). McGinnis and Ostrom (2014) differentiate between operational-choice rules (GS 5, rules at the level of individual actions), collective-choice rules (GS 6, determination of which rules are available at the operational level) and constitutional-choice rules (GS 7, rules determining who makes choices at the other two levels). While the German legal framework makes provisions at all three levels, the operational-choice rules found in agri-environmental law are particularly relevant for the management of agroforestry systems by farmers and were selected as a focus of analysis. German agri-environmental law differentiates between 'subsidy law' and 'command-control law' (Ramsauer, 2024). The term 'subsidy' law describes the formal rules regulating the provision of subsidies through state funds (Ramsauer, 2024, p. 213, e.g. CAP subsidies). In contrast, 'command-and-control' law contains the prohibitions, commandments or permissions that regulate the management of agroforestry systems by farmers (Ramsauer, 2024, p. 195, e.g. protection of orchard meadows in German nature conservation law). The formal rules in agri-environmental law are implemented by administrative staff, for example by deciding upon the

Table 1
Overview and definition of first-tier variables in the SES framework (McGinnis and Ostrom, 2014) and its operationalization for the analysis the legal framework for agroforestry in Germany.

First-tier variable (McGinnis and Ostrom, 2014)	Definition (McGinnis, 2011, p. 181, if not indicated otherwise)	Application to agroforestry (see also Guimarães et al., 2018; Torralba et al., 2018)	Selected second-tier variable (McGinnis and Ostrom, 2014)
Social, economic and political settings (S)	"The broader context within which the governance system per se is located, including the effects of market dynamics and cultural change."	The broader context that impacts the management and interventions in agroforestry systems, e.g. market dynamics for agroforestry products	No second-tier variable selected
Resource system (RS)	"The biophysical system from which resource units are extracted and through which the levels of the focal resource are regenerated by natural dynamic processes."	Single agroforestry systems, e.g. orchard meadows, hedgerow systems, alley cropping systems, grazed forests and the ecosystem functions and services produced by them.	RS 5 – Productivity of the system: Any material or immaterial benefit provided by the resource system
Governance system (GS)	"The prevailing set of processes or institutions through which the rules shaping the behavior of the users are set and revised."	Any institutions or rules that shape the behavior of actors with regard to agroforestry	GS5 – Operational-choice rules: Rules impacting the behavior of farmers in the focal action situation.
Resource units (RU)	"Characteristics of the units extracted from a resource system, which can then be consumed or used as an input in production or exchanged for other goods or services."	Components of the agroforestry system in question, e.g. trees, shrubs, cattle, crops, grasslands	No second-tier variable selected
Actors (A)	"The individuals who routinely extract resource units from that resource system; these users may or may not be organized into a single user group." (changed by McGinnis and Ostrom, 2014 to any actor involved in the management or governance of the resource system)	Actors directly or indirectly involved in the management or interventions on agroforestry systems: Farmers, landowners, advisors, administrative staff, tourists, consumers	No second-tier variable selected
Action situations: Interactions (I) Outcomes (O)	"[…] all the action takes place as inputs are transformed by the actions of multiple actors into outcomes." (McGinnis and Ostrom, 2014, p.4)	Pattern of interactions between actors (see above) and their management or interventions in agroforestry systems. From the interaction, multiple outcomes, including benefits and risks for the provisioning of ecosystem functions and services emerge.	I1 – Harvesting (and management) O2 – Ecological performance measures: Sustainability (multifunctionality)
Related ecosystems (ECO)	"The broader ecological context within which the focal resource system is located, including the determinants of many potential exogenous influences."	The broader ecological context within the respective agroforestry system is located, e.g. the effect of landscape composition and climate change.	No second-tier variable selected

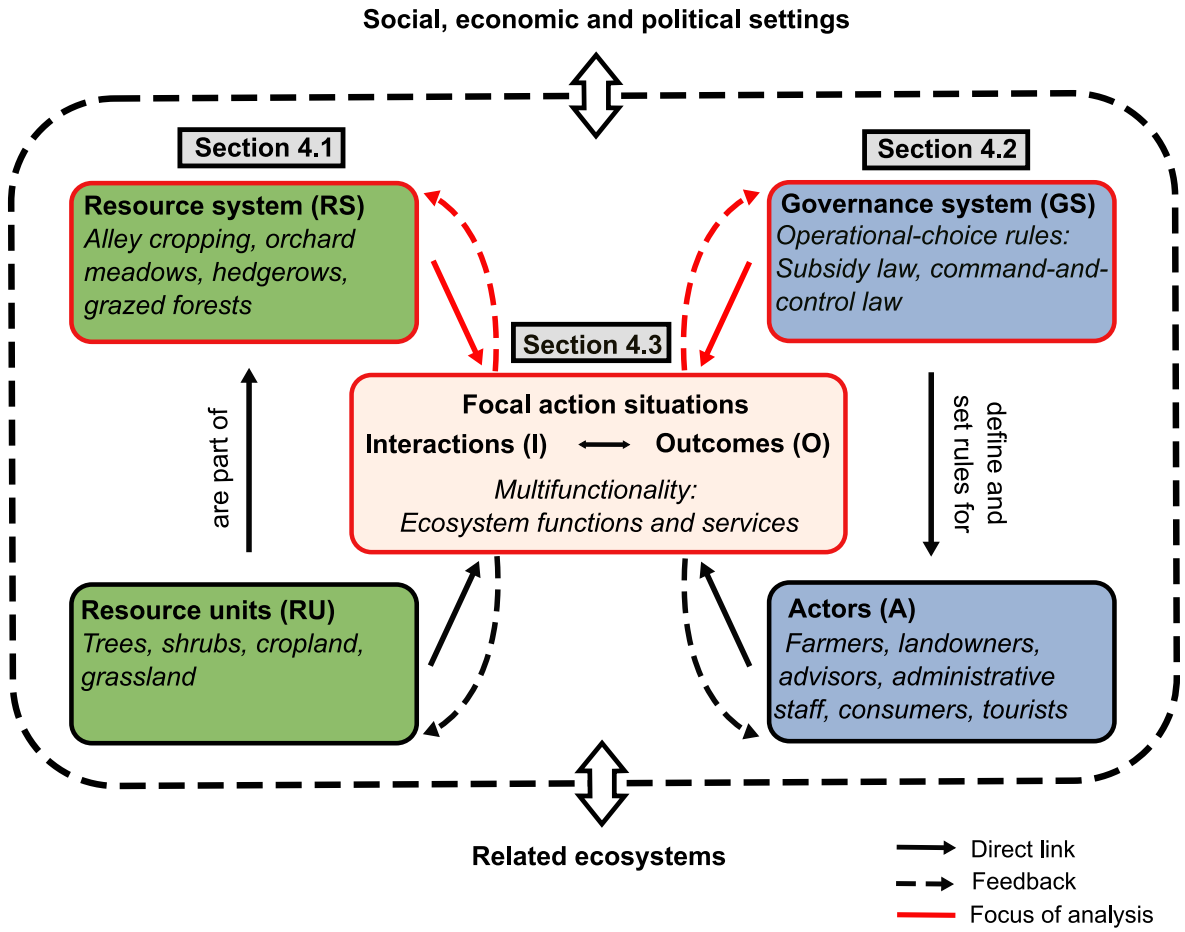

Fig. 1. SES-based analytical framework for the analysis of the legal framework for agroforestry (general framework adapted from Torralba et al. (2018, p. 3) and McGinnis and Ostrom (2014, p. 4)). The focus of analysis and the sections in the paper that address the respective first-tier variables are indicated.

issue of subsidies and permits to farmers. Moreover, at the local, state, federal and EU level, staff in ministries and politicians decide upon the revision and creation of laws with influence on agroforestry. They are thus also relevant actors in German agroforestry.

With regard to the outcome of the focal action situation, the SES framework differentiates between social performance measures (O1, e.g. equity), ecological performance measures (O2, e.g. sustainability) and externalities to other SES (O3). In the case of agroforestry in Germany, the simultaneous provisioning of multiple ecosystem functions and services ('multifunctionality', Manning et al., 2018, p. 427) is a major incentive for the promotion and adoption of agroforestry (BMEL, 2024a, p. 610) and was thus selected for further analysis in this paper. While McGinnis and Ostrom (2014) do not list multifunctionality as a third-tier variable in their original list of variables, it is seen as one cornerstone that contributes to the sustainability of SES (Kremen and Merenlender, 2018; Torralba et al., 2018). Inherent to the understanding of interactions in SES is the assumption that next to benefits, (economic) costs can be associated with a given interaction (Ostrom, 2009, p. 420). This notion is particularly relevant for the analysis of the outcome of agroforestry for multifunctionality. Indeed, the management of agroforestry systems can result not only in synergies, but also in trade-offs, "when the provision of one ES is reduced as a consequence of increased use of another ES" (Rodríguez et al., 2006, p. 2). In pursuit of this understanding, the SES framework has been applied to analyze not only the provision of single ecosystem services, but also associated synergies and trade-offs for the provision of multiple ecosystem functions and services of agroforestry systems (Torralba et al., 2018).

In the following, we discuss how this conceptualization of agroforestry as SES can inform the analysis of the legal framework for agroforestry in Germany.

2.3. Operationalization of the SES framework for legal sciences

The SES framework provides an entry point for applying a systems perspective in the legal analysis of a concrete legal framework. Importantly, the SES framework allows to disentangle the complex interactions between legal, social and ecological dynamics and the role of the law in shaping these dynamics. Moreover, in face of the difficulties of addressing current environmental challenges in the law, scientists call for a transformation of current laws (Kotzé and Kim, 2019; Bohman, 2021). To address this claim, it is required to analyze the law not only from the perspective of 'de lege lata' ('the law as it is') but also from the perspective of 'de lege ferenda' ('the law as it ought to be'). Since multifunctionality is a key component of the sustainability of agroforestry (O2), it can be hypothesized that it is required ('de lege ferenda') that the provisions in agri-environmental law ('operational-choice-rules', GS 5) allow farmers (A) to establish, manage and harvest (I) agroforestry systems in a way that maximizes their potentials and minimizes risks for the provisioning of multiple ecosystem functions and services (RS 5) and ultimately results in a positive outcome for multifunctionality (O2). This perspective on the function of law in SES may inform legal research in several ways. For example, one can analyze to what extent the legal instruments are designed to fulfill this function, how the law is applied or how the law interacts with other social-ecological dynamics (see also Du Plessis, 2023, p. 23 for the possible research foci of non-doctrinal legal research). The first question is fundamental and is the focus of this paper.

We conduct this analysis in three steps. Firstly, we review the main benefits and risks associated with different types of agroforestry systems

Table 2
Multifunctionality-related benefits and risks of agroforestry systems found in Germany for specific ecosystem functions and services.

Main benefits and risks for ecosystem functions and services	References
Orchard meadows	
• Benefits through the production of edible fruits, but economic risks for farmers, as costs for the maintenance of orchard meadows often exceed economic returns • Cultural heritage and benefits for landscape aesthetics • Benefits through the promotion of structural heterogeneity and provision of diverse ecological niches and habitats, high species diversity	Herzog (1998); Weller (2014); Plieninger et al. (2015)
Hedgerows	
• Economic risks: Management costs and trade-offs between agricultural yield and regulating services • Benefits for habitat connectivity and provision of diverse ecological niches and habitats, high species diversity • Benefits for the prevention of soil erosion by reduced wind speed and water runoff • Benefits as riparian buffer against nutrient input from agricultural fields	Baudry et al. (2000); García de Jalón et al. (2018); Montgomery et al. (2020); Collier (2021)
Alley cropping	
• Benefits through the creation of a microclimate beneficial for crop growth, often increased productivity • Economic risks due to high establishment costs and volatile wood prices • Benefits for biodiversity through the promotion of structural heterogeneity and provision of habitats, but risks for biodiversity conservation dependent on the landscape context • Benefits for carbon sequestration in biomass and soil	Böhm et al. (2011); Tsonkova et al. (2012); Mupepele et al. (2021b)
Grazed forests	
• Economic risks, risks for vegetation biomass and forest growth depending on the landscape-context • Cultural heritage • Benefits for biodiversity through the promotion of structural heterogeneity and provision of diverse ecological niches and habitats, high species diversity	Luick (2009); Bergmeier et al. (2010); Öllerer et al. (2019)

for specific ecosystem functions and services (RS 5, section 4.1). Secondly, we identify the principal provisions in subsidy and command-and-control law at the EU, federal and state level that currently regulate agroforestry systems in Germany (GS 5, section 4.2). Thirdly, we analyze to the extent to which the current legal framework enhances the benefits and minimizes the risks of agroforestry systems for specific ecosystem functions and services and thus allows farmers to manage their agroforestry systems with a positive outcome for multifunctionality (O2, section 4.3). Such a differentiated 'de lege lata' analysis is a prerequisite for developing tailored recommendations for a reform of legal provisions that embraces the multifunctionality of agroforestry systems as a regulatory target ('de lege ferenda' perspective). In the terminology of the SES framework, this paper analyzes current operational-choice rules for the management of agroforestry systems to be found in German agri-environmental law and examines the extent to which they meet their function in the governance of SES.

3. Materials and methods

In preparation of the legal analysis, the benefits and risks associated with different types of agroforestry systems for ecosystem functions and services such as biodiversity, soil and water quality, carbon sequestration, agricultural production, landscape aesthetics and cultural heritage were determined through a literature review. To account for the context-dependency and variety of benefits and risks of different agroforestry systems for ecosystem functions and services (Eichhorn et al., 2006; Torralba et al., 2016; Mupepele et al., 2021b), we included both modern and traditional agroforestry systems in our analysis. Consequently, we focused on alley cropping systems, orchard meadows, hedgerows and grazed forests as four agroforestry systems to be found in Germany (Nerlich et al., 2013). Relevant literature was identified through a search in the databases Web of Science and Google Scholar, searching for a combination of the terms 'agroforestry', 'alley cropping', 'hedgerow' and 'orchard meadow' and terms focusing on the ecosystem functions and services named above.

Secondly, we addressed the legal framework for agroforestry. We reviewed legal documents at the EU, German federal and state level (Supplementary Material A), focusing on rules in subsidy law and command-and-control law in the field of agri-environmental law. Due to the hybrid nature of agroforestry, next to agricultural law, nature conservation law and forest law are relevant for the management of agroforestry systems by farmers. Moreover, water law was included in the analysis, as it regulates the management of agroforestry close to water bodies. To account for Germany's federal structure, we included state law in our analysis and focused on Lower Saxony (north-west Germany), Brandenburg (north-east Germany) and Baden-Württemberg (south-west Germany). In a first step, we identified legal primary sources at the EU, federal and state level in the relevant legal databases maintained by the EU, Germany and the three states as well as by reviewing secondary literature. All primary legal sources were first screened for the agroforestry-related terms 'tree', 'shrub', 'field copse', 'woody perennial', 'hedge', 'orchard meadow', 'wood pasture', 'grazed forest', 'alley cropping' or 'agroforestry'. The applicability of all legal instruments to agroforestry was interpreted according to the doctrinal legal research method of legal interpretation (i.e. grammatical, systematical, teleological and historical interpretation of the text, Brugger, 1994). In total, 47 primary legal sources were selected for further analysis (Supplementary Material A).

Thirdly, we analyzed the extent to which the legal provisions account for the benefits and risks of agroforestry for ecosystem functions and services. In the terminology of the SES framework, we examined to what extent legal provisions amount to operational-choice rules that steer farmers to establish, manage and harvest agroforestry systems in a way that enhances benefits and minimizes risks for multiple ecosystem functions and services and thus results in their multifunctionality. To this end, scientific literature, legal commentaries, court decisions, explanatory memoranda published by the legislator, grey literature and position papers by nature conservation and agricultural associations on agroforestry law in Germany (76 sources in total, Supplementary Material B) were identified through the databases Google, Google Scholar, Beck online and Juris (German specific legal databases). All literature sources were reviewed with regard to information on the applicability and impact of the law on ecosystem functions and services associated with agroforestry. In addition, snowball-sampling was applied to further extend the literature base. Based on the identified literature, we interpreted the role of law in enhancing benefits and minimizing risks associated with agroforestry for ecosystem functions and services. The analysis presented here is based on the legal framework that was in force

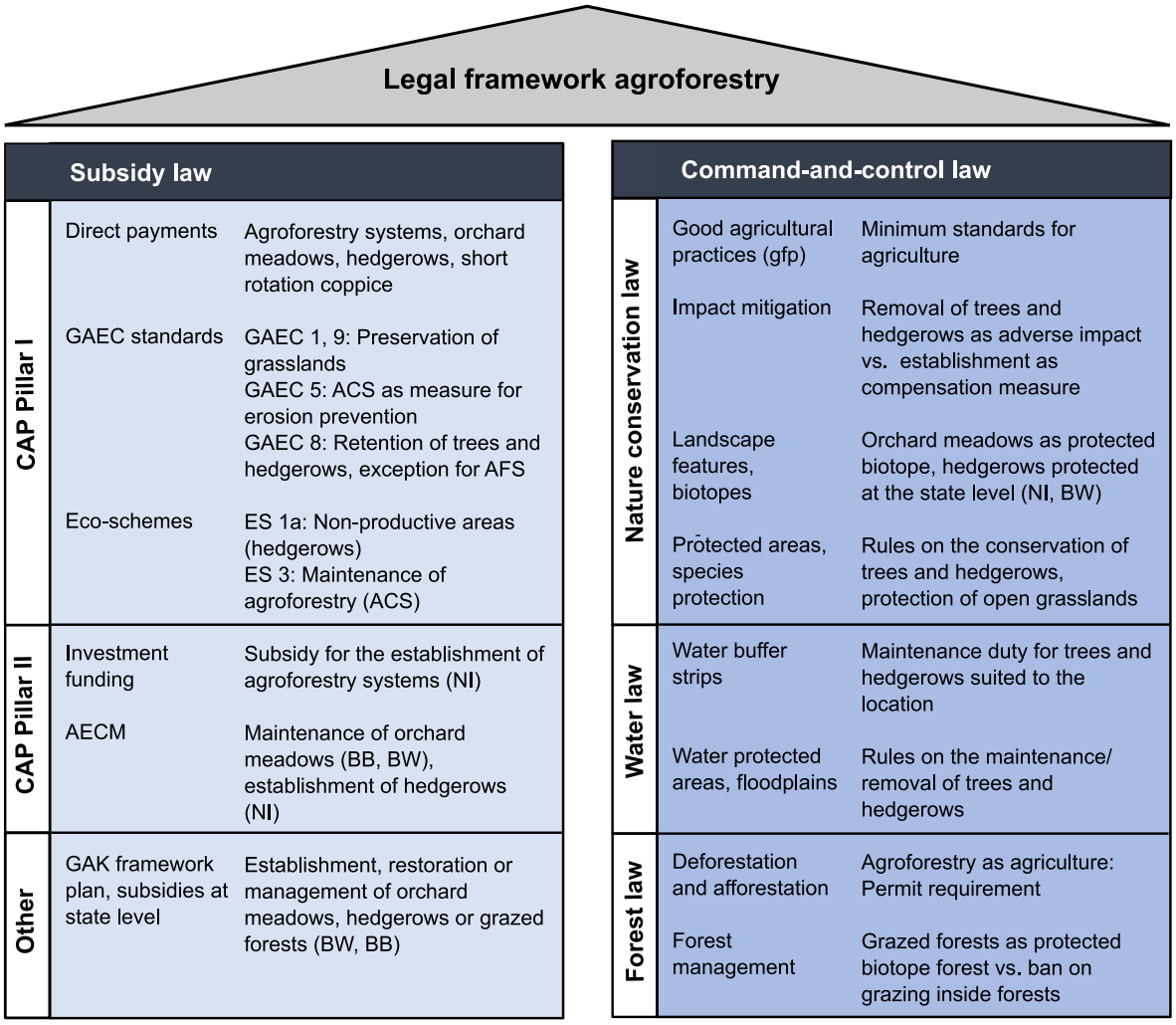

Fig. 2. Overview of instruments from subsidy law (left column) and command-and-control law (right column, nature conservation law, water law and forest law) with relevance for agroforestry in Germany. BB: Brandenburg, BW: Baden-Württemberg, NI: Lower Saxony. For all legal documents considered and for further details on the legal instruments see Supplementary Material A, C1 and C2.

on 20 December 2023.[1]

4. Results

4.1. Resource system – ecosystem functions and services

The diversity of modern and traditional agroforestry systems in Germany results in a variety of benefits and risks for ecosystem functions and services (RS 5, Table 2). They are dependent on the type of agroforestry system, the landscape context and the comparator system (Torralba et al., 2016; Mupepele et al., 2021b).

Orchard meadows describe agroforestry systems where different fruit trees of various age are dispersed in grasslands (Table 2, Eichhorn et al., 2006, p. 36). Trees are typically planted in densities of 20–100 trees/ha, either scattered over the agricultural parcel or planted in rows (Herzog, 1998, p. 62). Hedgerows are defined as linear arrangements of shrubs and trees that are managed by humans to control their size (Baudry et al., 2000, p. 8). Orchard meadows and hedgerows are especially valued for their contribution to biodiversity, but economically, they are not competitive with intensive agriculture (Table 2). Additionally, orchard meadows have a high cultural value, while hedgerows can function as a windbreak or riparian buffer strip (Table 2). In contrast, alley cropping systems (ACS) describe a modern design of agroforestry compatible with the use of machinery (Morhart et al., 2014, p. 530). Trees are planted in rows within agricultural fields (Quinkenstein et al., 2009, p. 1113) and usually either biomass or timber is produced from the tree component (Morhart et al., 2014, p. 530). Compared to hedgerows and orchard meadows, ACS are more production-oriented and can provide benefits for agricultural production, income diversification and carbon sequestration (Table 2). They can increase the structural diversity at landscape level and promote species diversity, but their effect on biodiversity is dependent on the landscape context.

Grazed forests describe the grazing of livestock within established forests that are dominated by old, tall deciduous trees such as oaks (*Quercus petraea, Q. robur*), beech (*Fagus sylvatica*) and hornbeam (*Carpinus betulus*, Bergmeier et al., 2010, p. 2999). Once a typical land use practice for feeding livestock, the growing demand for wood and degradation of forests led to legal restrictions and the abandonment of grazed forests from the 18th and 19th centuries onwards (Luick, 2009, p. 364). Today, forests and pasture are usually strictly separated and grazed forests are only very seldom found in Germany (Jedicke, 2013, p.

[1] As of the date of acceptance of the manuscript, no major changes have been adopted for the legal primary sources analyzed for this paper. Changes to federal funding schemes for agroforestry are under discussion, but have not yet been adopted.

Table 3
Definition, land use category and management requirements for different types or elements of agroforestry systems under the CAP post-2023 in the EU and their implementation in Germany. For a full citation of legal sources see Supplementary Material A.

	Definition	Land use category	Management requirements
Agroforestry (Sect. 4 II GAPDZV)	• Raw material or food production as primary goal • Audited use concept • Plants not listed in Annex I GAPDZV • Minimum of two strips that cover a maximum of 40 % of the agricultural parcel or 50 to 200 woody perennials/ha	Agroforestry on grassland, arable land or permanent culture	Requirements of the land use system in question Limitation of the cutting period, but removal of woody component possible (Sect. 23 II GAPKondV)
Orchard meadows (Sect. 7 IX GAPDZV, CAP Strategic Plan, p. 684)	• Stone fruit, pome fruit and wild fruit trees with large or medium trunk-height, • Tree densities of usually a maximum of 100 trees/ha	Permanent grassland	GAEC 1 and 9: Permit requirement for grassland conversion/Ban on conversion of environmentally-sensitive permanent grassland in Natura (2000) sites
Hedgerows (Sect. 11 I GAPDZV, Sect. 23 I No. 1 GAPKondV)	• Linear structural elements • Mostly covered by woody plants • Minimum length of 10 m, average width of up to 15 m • OR: Size of up to 500 m^2 per hedgerow if all such other woody perennials cover no more than 25 % of the agricultural parcel	Landscape feature on grassland, arable land or permanent culture	GAEC 8: Removal of the woody component prohibited, limitation of the cutting period

46). Grazed forests are valued for their contribution to biodiversity and their cultural importance as a traditional land use system (Table 2). However, compared to either modern forestry or agriculture, grazed forests are economically not competitive, and browsing, grazing and trampling by livestock can have negative effects on forest growth and traditional forest habitats (Table 2).

This brief review illustrates the multifunctionality-related benefits and risks for ecosystem functions and services associated with agroforestry systems in Germany (RS 5). In the following, we give an overview of the main legal provisions that regulate the establishment, management and harvesting of agroforestry systems by farmers (operational-choice rules, GS 5).

4.2. Governance system – main legal provisions

The legal framework applicable to agroforestry in Germany shapes the operational-choice rules (GS 5) for the actions of farmers. It encompasses several sectoral laws and is characterized by a high complexity. With the exception of the Common Agricultural Policy, the term 'agroforestry' is rarely mentioned directly in the law, but agroforestry systems are subject to various regulations for the promotion or protection of trees and shrubs (Fig. 2, Supplementary Material C1 and C2). In the following, we distinguish between subsidy law and command-and-control law (Ramsauer, 2024). We first focus on the Common Agricultural Policy (CAP) and its implementation in Germany ('subsidy law'), before giving an overview of the main legal provisions found in command-and-control law in the fields of German nature conservation, forest and water law.

The CAP provides subsidies for agricultural areas (in Germany roughly 6 billion euros per year between 2023 and 2027, BMEL, 2023, p. 10) and is based on two pillars. CAP subsidies are contingent on the maintenance of good agricultural and environmental conditions (GAEC standards). Pillar I offers annual subsidies per eligible hectare of an agricultural holding ('direct payments', in Germany roughly 70 % of the CAP subsidies, BMEL, 2023, p. 10). Agroforestry systems have been eligible for these subsidies since 2023. In Germany, 23 % of the budget for direct payments is dedicated to payments coupled to environmentally-friendly farming practices (eco-schemes, BMEL, 2023, p. 10). They include a subsidy for the maintenance of agroforestry systems (eco-scheme 3, 200 €/ha covered by trees or shrubs) and funding for the provision of non-productive areas (eco-scheme 1a, e.g. hedgerows). Pillar II is based on voluntary measures offered by the member states and implemented at the state level in Germany. It can include support for investments in agroforestry systems and agri-environment climate measures (AECM) aimed at promoting environmentally-friendly farming practices. While no AECM is explicitly dedicated to agroforestry in the CAP post-2023 in Germany, some federal states have established AECMs on orchard meadows or hedgerows (Fig. 2, Supplementary Material C1). The definition of agroforestry introduced at the German federal level as a result of the latest revision of the EU CAP (Table 3) is crucial for receiving funding. Although orchard meadows and hedgerows are recognized as traditional types of agroforestry systems, they do not fall under this definition. Instead, orchard meadows are defined as permanent grasslands, while hedgerows are defined as landscape features that are protected from removal. In addition, short rotation coppice (SRC) is recognized separately under the CAP.

In addition to the definition as an eligible hectare under pillar I of the CAP (Table 3), funding through the eco-scheme for the maintenance of agroforestry systems is tied to further requirements such as a strip width of 3–25 m, a distance of minimum 20 m and maximum 100 m between the strips and to the border of the parcel, and a share of woody perennials of 2–35 % of the total area of the agricultural parcel (Supplementary Material C1).

Additionally, the "Joint task for the improvement of agricultural structures and coastal protection" (GAK) coordinates joint subsidy programs between the German federal level and the federal states, including the implementation of Pillar II of the CAP. It includes a newly introduced funding scheme for the establishment of agroforestry systems as well as subsidies for the integration of natural landscape features into arable fields (e.g. hedgerows), sustainable management of fruit stands (e.g. orchard meadows), investments in non-productive measures for nature conservation (e.g. hedgerows) and funding for nature conservation contracts (Supplementary Material C1).

Command-and-control law is largely determined by provisions of nature conservation, water and forest law (Fig. 2, Supplementary Material C2). Agroforestry systems are not defined as such in the Federal Nature Conservation Act (BNatSchG) and according to the interpretation by a German administrative court, they do not fall under the privileges granted to agriculture by nature conservation law (VG Hannover, 2022). Thus, the woody component of agroforestry systems may be subject to a number of legal provisions for the protection of woody landscape features (Fig. 2, Supplementary Material C2), including provisions on good agricultural practices, impact mitigation, legal protection of natural monuments, landscape features and biotopes, species protection and protected areas. These provisions generally aim to protect trees and shrubs and include a prohibition or permit requirement for the harvesting or removal of trees and shrubs. Additionally, water law regulates the management of woody plants next to water bodies and in flood and water protection areas (Fig. 2, Supplementary Material C2) and limits

the establishment and removal of trees and shrubs in these areas. The management of forests is regulated by the Federal Forest Act (BWaldG) and state forest acts (Fig. 2, Supplementary Material C2). It exempts agroforestry from regulation under forest law and therefore limits the establishment of agroforestry on areas recognized as forests. While historic, formerly grazed forests can be protected as biotope conservation forests, grazing within forests usually interferes with rules on forest management criteria and is prohibited at the state level.

Overall therefore, operational-choice rules (GS 5) emerge from both subsidy law and command-and-control law. While often not naming agroforestry, they target woody vegetation and thus influence the ways farmers may establish, manage and harvest their agroforestry systems. Building on the findings presented in sections 4.1 and 4.2, the following section examines the extent to which the current legal framework results in operational-choice rules that steer farmers to establish, manage and harvest agroforestry systems in a way that maximizes benefits and minimizes risks of agroforestry systems for ecosystem functions and services and thus results in multifunctionality.

4.3. The role of the law in the governance of agroforestry

While some legal instruments take into account the

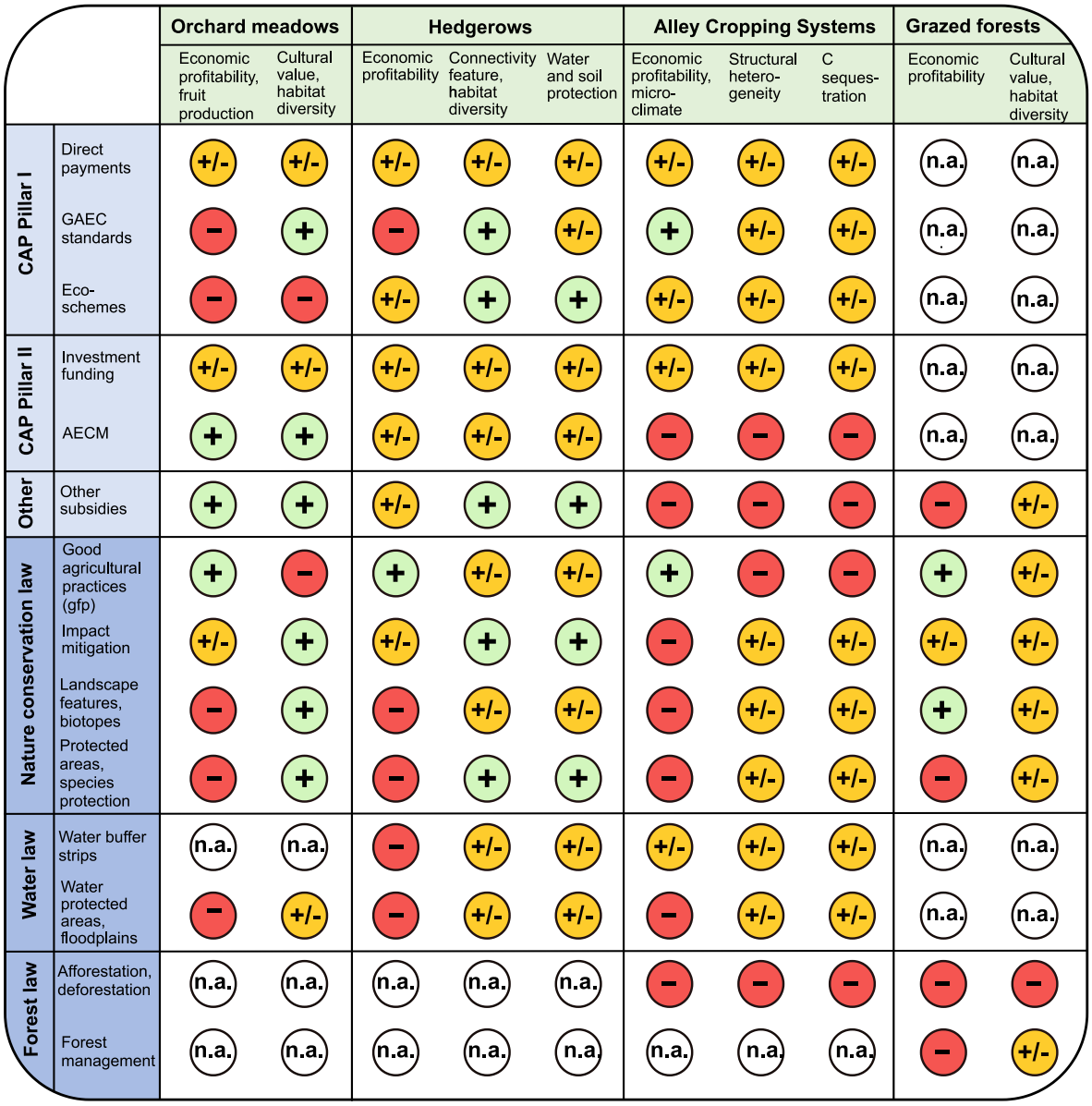

Fig. 3. The extent to which principal provisions in subsidy law, nature conservation law, water law and forest law enhance benefits and minimize risks of agroforestry systems for specific ecosystem functions and services. Green: Resource system and the respective ecosystem functions and services identified for each of the four agroforestry systems (RS 5, Section 4.1). Blue: Legal provisions shaping the operational-choice rules of the governance system (GS 5, section 4.2), differentiating between subsidy laws (light blue) and command-and-control laws (dark blue). For each agroforestry system, the extent to which the legal provisions account for the benefits and risks for ecosystem functions and services has been assessed separately based on legal interpretation of legal sources and secondary literature (see section 3). Red (-): No eligibility for the respective subsidy or regulation not responsive to the benefits or risks for the respective ecosystem function or service. Green (+): Eligible for funding and regulation responsive to the benefits and risks for the respective ecosystem function or service. Yellow (+/-): Eligible for funding and regulation responsive to benefits and risks for the respective ecosystem function or service, but there are case-dependent constraints. White (n.a.): The legal instrument does not apply to the agroforestry system in question or is of minor relevance. For an extended explanation of our analysis and sources used for interpretation see Supplementary Material B and C3. For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.

multifunctionality of agroforestry systems, particularly with regard to the conservation of existing orchard meadows and hedgerows, the law leaves little room for the active management of orchard meadows and hedgerows by farmers. Moreover, current agri-environmental laws do not address the lack of economic profitability of agroforestry systems, do not balance the benefits and risks arising from alley cropping systems for ecosystem functions and services and largely neglect the ecological benefits of grazing inside forests. Fig. 3 summarizes the extent to which principal provisions in subsidy law, nature conservation law, water law and forest law enhance benefits and minimize risks of the four agroforestry systems to be found in Germany with respect to specific ecosystem functions and services. Red and yellow dots highlight the mismatches between current legal provisions and benefits and risks of the different types of agroforestry systems to specific ecosystem functions and services. In the following, we highlight main shortcomings in subsidy and command-and-control law.

4.3.1. Subsidies for agroforestry systems

While the eligibility of agroforestry systems for agricultural subsidies is an essential prerequisite for their establishment by farmers (Mosquera-Losada et al., 2018; Tsonkova et al., 2018), current funding schemes for agroforestry in Germany largely exclude orchard meadows and hedgerows, for example by requiring that the woody plants have a predominantly productive purpose. Likewise, low funding rates, size restrictions for hedgerows, bureaucratic requirements (e.g. the submission of a use concept for agroforestry systems) and detailed provisions regarding the design of agroforestry systems hinder farmers to make use of available subsidies and establish agroforestry systems in the first place (Supplementary Material C3).

With regard to the benefits and risks of agroforestry systems for ecosystem functions and services, the GAEC standards are supposed to define environmental requirements for agricultural management in subsidy law. However, current requirements only partly account for benefits and risks of agroforestry systems for ecosystem functions and services (Fig. 3, Supplementary Material C3). For example, the GAEC standards do not address possible risks of ACS for biodiversity conservation, they hinder the active management of hedgerows by farmers to enhance their economic profitability and do not recognize the role of hedgerows in erosion control and protection of water bodies (Fig. 3, Supplementary Material C3).

Similarly, the eco-scheme for the maintenance of agroforestry contains detailed provisions on the design of agroforestry systems, applies only to productive ACS and has low funding levels compared to other CAP subsidies (Klimke and Zengerling, 2024) (Fig. 3, Supplementary Material C3). Consequently, it was little requested by famers in 2023 and 2024 despite an increase in funding height from 60 €/ha covered by woody vegetation to 200 €/ha covered by woody vegetation in 2024 (only 51 ha in 2023 and 173 ha in 2024, BMEL, 2024b). Moreover, although the German CAP Strategic Plan emphasizes the multifunctional purposes of agroforestry, the eco-scheme applies mainly to ACS, does not differentiate between different types of agroforestry systems and is not tailored to their benefits and risks for different ecosystem functions and services (Fig. 3, Supplementary Material C3).

Pillar II of the CAP focuses more on environmental aspects, but the subsidy schemes established under pillar II at the state level (e.g. agri-environment climate measures, investment funding) also have no focus on promoting the benefits of agroforestry systems for ecosystem functions and services (Fig. 3, Supplementary Material C3). Importantly, no agri-environment climate measure (AECM) is explicitly dedicated to agroforestry, although agroforestry is mentioned as a means of achieving environmental objectives such as climate change mitigation and adaptation in the CAP Strategic Plan. Likewise, nature conservation funding and the AECM tailored to orchard meadows and hedgerows focus on promoting the contribution of these traditional agroforestry systems to nature conservation targets such as habitat provisioning, but are not applicable to modern agroforestry systems such as ACS (Klimke and Zengerling, 2024). While this is consistent with the critical assessment of agroforestry systems by ecologists (Pe'er et al., 2017), it precludes the opportunity to promote the benefits of different types of agroforestry systems for ecosystem functions and services by a tailored AECM. Additionally, the newly introduced subsidy for the establishment of agroforestry systems under the CAP and the GAK framework plan ('investment funding') does not focus on promoting the benefits of agroforestry for ecosystem functions and services and suffers from a lack of implementation by the federal states.

4.3.2. Protection of woody perennials in command-and-control law

Impact mitigation (Sect. 13 et seq. BNatSchG), the legal protection of landscape features and biotopes (Sect. 29, 30 BNatSchG) and species protection law (Sect. 39, 44 BNatSchG) encompass key legal provisions for the preservation of woody landscape features and their benefits for ecosystem functions and services (Fig. 3, Supplementary Material C3). On the one hand, the lack of full protection for hedgerows at the federal level (i.e. as protected biotope, Köck, 2019) and the lack of recognition of traditional agroforestry systems such as grazed forests as biotopes of community interest under the EU Habitats Directive are obstacles to maintaining the benefits of agroforestry for ecosystem functions and services (Fig. 3, Supplementary Material C3). On the other hand, the protection of woody perennials limits the economic use of agroforestry systems by farmers and hinders their establishment and active management (Tsonkova et al., 2018). Similarly, restrictions on the establishment of ACS on grasslands or in nature conservation areas are consistent with recommendations for their protection, but create restrictions for benefits for other ecosystem functions and services by ACS.

The lack of a direct recognition of agroforestry in the German federal nature conservation law (BNatSchG) exacerbates these conflicts and results in legal uncertainties as to whether the privileges granted to agricultural land use apply to agroforestry (Klimke and Zengerling, 2024). The good agricultural practices (Sect. 5 II BNatSchG) could balance the relationship between the protection and use of woody perennials in the context of agroforestry systems. However, by not specifying agroforestry and by being a mere guideline ('Handlungsdirektive') and not a requirement ('Gebot') or prohibition ('Verbot'), they are of little practical relevance (Fig. 3, Supplementary Material C3). Furthermore, nature conservation law does not include any obligation to promote trees or shrubs and therefore does not promote the establishment of new agroforestry systems.

4.3.3. Water and forest law

With regard to the Federal Water Act (WHG), the ban on removing trees and shrubs from riparian buffer strips protects the nutrient interception by trees and shrubs. However, restrictions on the establishment or removal of trees and shrubs can hinder the establishment of agroforestry systems (Fig. 3, Supplementary Material C3). First examples in state law show how these interests can be balanced by carefully designed exemptions that allow for the establishment and management of trees in water buffer strips.

Current German forest laws counteract the idea of promoting the multifunctional purposes of agroforestry by maintaining the separation into forestry and agriculture (Fig. 3, Supplementary Material C3). The German Forest Act defines agroforestry as areas covered by trees that simultaneously serve the purpose of agricultural production. While ACS under active management clearly fall under the definition of agroforestry, changes in management objectives such as the abandonment of agriculture can lead to ACS being classified as illegal afforestation. In addition, the contradiction between the prohibition of grazing within forests and the consideration of grazed forests for the mapping of forest functions or as a compensation measure (Annex 6 A BKompV) illustrates a conflict between forest law and nature conservation targets.

In summary, our analysis has identified two significant shortcomings of the legal framework in shaping the operational-choice rules for farmers. Firstly, current legislation is a major disincentive for farmers to

establish agroforestry systems in the first place. Secondly, legal provisions in subsidy and command-and-control law do not adequately enhance benefits and minimize risks of agroforestry systems for specific ecosystem functions and services. Therefore, they reduce the degree to which farmers can establish, manage and harvest their agroforestry systems in a way that contributes to multifunctionality.

5. Discussion

In complementing studies on actor perceptions of agroforestry (García de Jalón et al., 2018; Tsonkova et al., 2018; Litschel et al., 2023), agroforestry-related laws and policies at the EU and German level (Böhm et al., 2017; Klimke and Zengerling, 2024; Mosquera-Losada et al., 2018; Santiago-Freijanes et al., 2018) and on the role of law in the governance of SES (Frohlich et al., 2018; Bohman, 2021), the aim of this article was twofold: Firstly, it provided an example of how to operationalize the social-ecological systems framework (SES framework) for ecosystem-tailored legal research at the case study level in the emerging field of agroforestry law. Secondly, in applying the SES framework, it identified in a differentiated manner if and to what extent principal provisions in subsidy law and command-and-control law steer farmers to establish, manage and harvest agroforestry systems in a way that enhances benefits and minimizes risks for multiple ecosystem functions and services and thus results in their multifunctionality. In the following, we first discuss the opportunities and challenges of using the SES framework to analyze the legal framework for agroforestry. The second part of the discussion relates our findings to key hurdles and possible adjustments proposed to agroforestry law in Europe and elsewhere.

The operationalization of the SES framework for legal analysis allowed for a differentiated and ecosystem-tailored analysis of main legal provisions combining doctrinal (Brugger, 1994) and non-doctrinal (Martin and Ruhl, 2023) legal research methods. The main challenge in the application of the SES framework was the selection of suitable second-tier variables. Given that Ostrom (2009) and McGinnis and Ostrom (2014) selected and defined such variables based on economic conceptions and terminology, we had to consider carefully whether and how such variables could be translated into an analysis of a legal framework. By selecting relevant second-tier variables for the resource system, governance system and the focal action situation, the approach enabled us to link the resource and the governance system of agroforestry in Germany with a view to strengthening multifunctionality of agroforestry systems. More specifically, we could demonstrate to what extent provisions from subsidy law and command-and-control law at the EU, federal and state level enhance benefits and minimize risks of different agroforestry systems for specific ecosystem functions and services (Fig. 3). Such findings could not have been derived from a mere doctrinal legal analysis.

Our results are consistent with the finding by other authors that agroforestry may contribute to political targets such as sustainable development, climate mitigation or biodiversity conservation globally (Santiago-Freijanes et al., 2021), but is limited in its application due to a lack of policy support, terminological constraints and incoherent policies at the national level in Europe and elsewhere (Simelton et al., 2017; Ndlovu and Borrass, 2021; Santiago-Freijanes et al., 2021). In the following, we summarize overarching hurdles for the adoption of agroforestry in Germany and discuss what the German case study can contribute to the general discussion on how to best promote agroforestry in the law.

Firstly, similar to studies on other jurisdictions including the EU (Simelton et al., 2017; Santiago-Freijanes et al., 2018; Mosquera-Losada et al., 2023) and Germany (Böhm et al., 2017; Klimke and Zengerling, 2024), our results show that agroforestry is not appropriately defined in German subsidy and command-and-control law. While this lack of a holistic definition mirrors the little coverage of agroforestry in most of Europe (Den Herder et al., 2017), the lack of a holistic definition that encompasses traditional as well as modern agroforestry systems is a fundamental constraint of the legal framework. Indeed, a clear legal definition of agroforestry systems in line with natural sciences' typology (Klimke and Zengerling, 2024) is essential for developing a coherent set of rules tailored to enhancing the multifunctionality of agroforestry systems. Although the need to introduce a legal definition for agroforestry in subsidy law (Böhm et al., 2017; Mosquera-Losada et al., 2018; Tsonkova et al., 2018) was addressed in the CAP post-2023 in Germany, the newly introduced definition does not capture the diversity of agroforestry systems present in Germany and creates a segregation between modern and traditional agroforestry systems. Additionally, the lack of a holistic definition of agroforestry in command-and-control law prevents the definition of minimum environmental requirements for agroforestry systems and results in contradictions and legal uncertainties for farmers. Therefore, our results reinforce the need to introduce a holistic legal definition for agroforestry (Simelton et al., 2017; Mosquera-Losada et al., 2023) that is applied across subsidy and command-and-control laws and that embraces modern and traditional agroforestry systems.

Secondly, our results for the German case study highlight contradictions in the current patchwork of laws applicable to agroforestry systems. For example, current subsidy law under the CAP collides with retention obligations for trees under German federal and state nature conservation law. As elsewhere (Ndlovu and Borrass, 2021), these incoherencies need to be addressed, for example by introducing an agricultural law at the European or national level (Czybulka et al., 2021; Klimke and Zengerling, 2024; Mupepele et al., 2021a). Additionally, we have shown that the federal structure in Germany results in different funding schemes and levels of protection for trees and shrubs at the state level. While federalism can enable the adaptation of law to regional needs (Torralba et al., 2018, p. 9), it can also create contradictions and conflicts. Therefore, state law on agroforestry systems should account for the regional context while ensuring coherence with the supra-state regulation.

Thirdly, our results highlight several mismatches between the current legal framework and benefits and risks of agroforestry systems for ecosystem functions and services (Fig. 3). As also found for other jurisdictions (Mauerhofer, 2018; Bell-James, 2019), agri-environmental law in Germany considers some ecosystem functions or services, but does not holistically address the provision of multiple ecosystem functions and services and thus overall multifunctionality. For example, the CAP's focus on production-oriented agroforestry systems, the lack of funding as well as distance and size requirements for trees and shrubs on agricultural parcels underline that the CAP promotes agricultural production. However, it does not enhance environmentally-friendly farming practices and the provision of public or environmental services (Mosquera-Losada et al., 2018; Pe'er et al., 2020). Further mismatches have been identified in nature conservation, water and forest law (Fig. 3). Therefore, if multifunctionality is recognized as a key regulatory target for agroforestry systems, current subsidy law and command-and-control law needs to be revised with a view to resolving these mismatches. For example, adjusting CAP subsidies to approaches such as 'payments for public goods' (Pe'er et al., 2020, p. 308) and a focus on measurable outcomes (Mupepele et al., 2021a, p. 1068) could promote agroforestry systems (Tsonkova et al., 2018) and their multifunctionality.

6. Conclusion

In view of the societal, economic and environmental challenges faced by agriculture in the European Union, a transformation of current farming systems is called for. In this context, agroforestry systems are a potential 'win-win solution' for environmental, economic and societal targets. Despite the prominent role of agroforestry systems in societal and scientific discourses, the legal framework and the outcomes of agroforestry systems for agricultural and environmental purposes have not been addressed in legal research as yet. Targeting this research gap,

we have shown that the current legal framework applicable to agroforestry systems in Germany has two significant shortcomings. Firstly, it is a major obstacle to the establishment of agroforestry systems by farmers. Secondly, legal provisions in subsidy law and command-and-control law do not adequately enhance benefits and minimize risks of agroforestry systems for specific ecosystem functions and services. Methodologically, we have adopted the social-ecological systems framework (SES framework) to analyze the role of law in promoting the multifunctionality of agroforestry systems in Germany. The role of law in shaping social-ecological dynamics has so far mostly been addressed from a meta-perspective with a focus on the agreement of general legal principles with concepts such as resilience or adaptive management. Here, we have provided a first example of how the SES framework can be combined with doctrinal legal research methods to analyze the role of law in shaping social-ecological dynamics.

Therefore, we were able to examine the legal framework and its implications for the sustainability of agroforestry from an interdisciplinary perspective. Importantly, the operationalization of the SES framework proposed here allowed us to analyze in a differentiated manner to what extent provisions in subsidy and command-and-control law at the EU, federal and state level account for benefits and risks of different agroforestry systems for ecosystem functions and services and thus steer farmers to establish, manage and harvest agroforestry systems in a way that promotes multifunctionality. We found that three major legal challenges stand out: Terminological misconceptions, contradictions between subsidy and command-and-control laws and a lack of tailored legal steering to enhance benefits and minimize risks of agroforestry systems for specific ecosystem functions and services hinder the promotion of agroforestry as part of a multifunctional farming landscape.

While such an analysis is a fundamental step when aiming towards the reform of a legal system, it is only the starting point for a systemic analysis of agroforestry law through the lens of the SES framework. Importantly, the interaction of the law with other social-ecological feedback processes, the implementation of the law and stakeholder views on agroforestry and the law are further important aspects to consider. Moreover, while our analysis has focused on subsidy, nature conservation, water and forest law as four legal spheres with major influence on agroforestry in Germany, private law and the prevalence of tenure are other factors that influence the adoption of agroforestry by farmers. In addition, newly adopted regulation such as the European Nature Restoration Law should be included in future research on agroforestry systems.

Funding

This article was written as part of the INTEGRA project. INTEGRA is supported by funds from the Federal Ministry of Food and Agriculture (BMEL) based on a decision of the parliament of the Federal Republic of Germany via the Federal Office for Agriculture and Food (BLE) under the Federal Programme for Ecological Farming and Other Forms of Sustainable Agriculture [support code 2819NA071]. The research was conducted independently of the funding agency and the views and opinions expressed as part of the article are solely those of the authors.

CRediT authorship contribution statement

Marina Klimke: Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Tobias Plieninger:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Cathrin Zengerling:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgements

We would like to thank Elisabeth Mallows for reviewing the language of an earlier version of the article.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.esg.2024.100223.

References

Anderies, J.M., Janssen, M.A., Ostrom, E., 2004. A framework to analyze the robustness of social-ecological systems from an institutional perspective. Ecol. Soc. 9 (1), 18. http://www.jstor.org/stable/26267655.

Baudry, J., Bunce, R., Burel, F., 2000. Hedgerows: an international perspective on their origin, function and management. J. Environ. Manage. 60 (1), 7–22. https://doi.org/10.1006/jema.2000.0358.

Bell-James, J., 2019. Integrating the ecosystem services paradigm into environmental law: a mechanism to protect mangrove ecosystems? J. Environ. Law 31 (2), 291–314. https://doi.org/10.1093/jel/eqz010.

Bergmeier, E., Petermann, J., Schröder, E., 2010. Geobotanical survey of wood-pasture habitats in Europe: diversity, threats and conservation. Biodivers. Conserv. 19 (11), 2995–3014. https://doi.org/10.1007/s10531-010-9872-3.

Binder, C.R., Hinkel, J., Bots, P.W., Pahl-Wostl, C., 2013. Comparison of frameworks for analyzing social-ecological systems. Ecol. Soc. 18 (4), 26. https://doi.org/10.5751/ES-05551-180426.

BMEL, 2023. Den Wandel gestalten! Zusammenfassung zum GAP-Strategieplan 2023 – 2027. Bundesministerium für Ernährung und Landwirtschaft. https://www.bmel.de/SharedDocs/Downloads/DE/_Landwirtschaft/EU-Agrarpolitik-Foerderung/gap-strategieplan-kurzueberblick.pdf?_blob=publicationFile&v=5. (Accessed 2 July 2024).

BMEL, 2024a. CAP Strategic Plan for the Federal Republic of Germany, 21 February 2024, Version 4.0.

BMEL, 2024b. Nachfrage nach Öko-Regelungen 2024 deutlich gestiegen – Anpassungen des BMEL zeigen Wirkung. Bundesministerium für Ernährung und Landwirtschaft. Press release of 1 July 2024. https://www.bmel.de/SharedDocs/Pressemitteilungen/DE/2024/062-oeko-regelungen.html. (Accessed 2 July 2024).

Böhm, C., Quinkenstein, A., Freese, D., Hüttl, R.F., 2011. Assessing the short rotation woody biomass production on marginal post-mining areas. J. For. Sci. 57 (7), 303–311. https://doi.org/10.17221/94/2010-JFS.

Böhm, C., Tsonkova, P., Albrecht, E., Zehlius-Eckert, W., 2017. Zur Notwendigkeit einer kontrollfähigen Definition für Agroforstschläge. Agrar Umweltr. 7–12.

Bohman, B., 2021. Legal Design for Social-Ecological Resilience. Cambridge University Press, Cambridge. https://doi.org/10.1017/9781108879101.

Brugger, W., 1994. Legal interpretation, schools of jurisprudence, and anthropology: some remarks from a German point of view. Am. J. Comp. L. 42, 395–422. https://heinonline.org/HOL/P?h=hein.journals/amcomp42&i=405.

Burgess, P.J., Rosati, A., 2018. Advances in European agroforestry: results from the AGFORWARD project. Agroforest. Syst. 92 (4), 801–810. https://doi.org/10.1007/s10457-018-0261-3.

CBD, 1992. Convention on Biological Diversity. United Nations.

CBD, 2000. Ecosystem Approach. Decision V/6, Doc. UNEP/CBD/COP/DEC/5/6.

CBD, 2022. Kunming-Montreal Global Biodiversity Framework. Decision 15/4, Doc. CBD/COP/DEC/15/4.

Collier, M.J., 2021. Are field boundary hedgerows the earliest example of a nature-based solution? Environ. Sci. Policy 120, 73–80. https://doi.org/10.1016/j.envsci.2021.02.008.

Czybulka, D., Fischer-Hüftle, P., Hampicke, U., Köck, W., Martinez, J., 2021. Ein Landwirtschaftsgesetz für Deutschland im Zeichen von Umweltschutz und Biodiversität – Notwendigkeit, Funktion und Leitbild. NuR 43 (4), 227–236. https://doi.org/10.1007/s10357-021-3825-3.

Den Herder, M., Moreno, G., Mosquera-Losada, R.M., Palma, J., Sidiropoulou, A., Santiago Freijanes, J.J., Crous-Duran, J., Paulo, J.A., Tomé, M., Pantera, A., Papanastasis, V.P., Mantzanas, K., Pachana, P., Papadopoulos, A., Plieninger, T., Burgess, P.J., 2017. Current extent and stratification of agroforestry in the European Union. Agric. Ecosyst. Environ. 241, 121–132. https://doi.org/10.1016/j.agee.2017.03.005.

Du Plessis, A., 2023. Non-doctrinal research to advance urban sustainability in the southern African context. In: Martin, P., Teles da Silva, S., Leuzinger, M., Verbeek, M., Lawson, A. (Eds.), Non-doctrinal Research Methods in Environmental Law. Edward Elgar, Cheltenham, pp. 20–37.

Eichhorn, M.P., Paris, P., Herzog, F., Incoll, L.D., Liagre, F., Mantzanas, K., Mayus, M., Moreno, G., Papanastasis, V.P., Pilbeam, D.J., Pisanelli, A., Dupraz, C., 2006. Silvoarable systems in Europe – past, present and future prospects. Agroforest Syst 67 (1), 29–50. https://doi.org/10.1007/s10457-005-1111-7.

European Commission, 2021. Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions. New EU Forest Strategy for 2030. COM/2021/572 final.

Frohlich, M.F., Jacobson, C., Fidelman, P., Smith, T.F., 2018. The relationship between adaptive management of social-ecological systems and law. Ecol. Soc. 23 (2), 23. https://doi.org/10.5751/ES-10060-230223.

García de Jalón, S., Burgess, P.J., Graves, A., Moreno, G., McAdam, J., Pottier, E., Novak, S., Bondesan, V., Mosquera-Losada, R., Crous-Durán, J., Palma, J.H.N., Paulo, J.A., Oliveira, T.S., Cirou, E., Hannachi, Y., Pantera, A., Wartelle, R., Kay, S., Malignier, N., van Lerberghe, P., Tsonkova, P., Mirck, J., Rois, M., Kongsted, A.G., Thenail, C., Luske, B., Berg, S., Gosme, M., Vityi, A., 2018. How is agroforestry perceived in Europe? An assessment of positive and negative aspects by stakeholders. Agroforest. Syst. 92 (4), 829–848. https://doi.org/10.1007/s10457-017-0116-3.

Guimarães, M.H., Guiomar, N., Surová, D., Godinho, S., Correia, T.P., Sandberg, A., Ravera, F., Varanda, M., 2018. Structuring wicked problems in transdisciplinary research using the Social–Ecological systems framework: an application to the montado system, Alentejo, Portugal. J. Clean. Prod. 191, 417–428. https://doi.org/10.1016/j.jclepro.2018.04.200.

Herzog, F., 1998. Streuobst: a traditional agroforestry system as a model for agroforestry development in temperate Europe. Agroforest. Syst. 42, 61–80. https://doi.org/10.1023/A:1006152127824.

Hinkel, J., Cox, M.E., Schlüter, M., Binder, C.R., Falk, T., 2015. A diagnostic procedure for applying the social-ecological systems framework in diverse cases. Ecol. Soc. 20 (1), 32. https://doi.org/10.5751/ES-07023-200132.

IPBES, 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. In: Díaz, S., Settele, J., Brondízio, E.S., Ngo, H. T., Guèze, M., Agard, J., Arneth, A., Balvanera, P., Brauman, K.A., Butchart, S.H.M., Chan, K.M.A., Garibaldi, L.A., Ichii, K., Liu, J., Subramanian, S.M., Midgley, G.F., Miloslavich, P., Molnár, Z., Obura, D., Pfaff, A., Polasky, S., Purvis, A., Razzaque, J., Reyers, B., Roy Chowdhury, R., Shin, Y.J., Visseren-Hamakers, I.J., Willis, K.J., Zayas, C.N. (Eds.). IPBES secretariat, Bonn, Germany. https://doi.org/10.5281/zenodo.3553579.

IPCC, 2022. Summary for Policymakers. In: Shukla, P.R., Skea, J., Calvo Buendia, E., Masson-Delmotte, V., Pörtner, H.-O., Roberts, D.C., Zhai, P., Slade, R., Connors, S., van Diemen, R., Ferrat, M., Haughey, E., Luz, S., Neogi, S., Pathak, M., Petzold, J., Portugal Pereira, J., Vyas, P., Huntley, E., Kissick, K., Belkacemi, M., Malley, J. (Eds.), Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Cambridge University Press, Cambridge. https://doi.org/10.1017/9781009157988.001.

Jedicke, E., 2013. Waldweide und Naturschutz – historische Vorbilder, aktuelle Ziele und Umsetzbarkeit. Nationalpark-Jahrbuch Unteres Odertal 10, 43–52.

Klimke, M., Zengerling, C., 2024. Aufwind für Agroforstsysteme? Aktuelle Entwicklungen, Chancen und Hemmnisse im europäischen und deutschen Recht. NuR in press.

Köck, W., 2019. Naturschutz und Landwirtschaft – eine Bilanz aus der Perspektive des Rechts. ZUR 30 (2), 67–74.

Kotzé, L.J., Kim, R.E., 2019. Earth system law: the juridical dimensions of earth system governance. Earth Syst. Gov. 1, 100003 https://doi.org/10.1016/j.esg.2019.100003.

Kozar, R., Djalante, R., Leimona, B., Subramanian, S.M., Saito, O., 2023. The politics of adaptiveness in agroecosystems and its role in transformations to sustainable food systems. Earth Syst. Gov. 15, 100164 https://doi.org/10.1016/j.esg.2023.100164.

Kremen, C., Merenlender, A.M., 2018. Landscapes that work for biodiversity and people. Science 362 (6412), eaau6020. https://doi.org/10.1126/science.aau6020.

Litschel, J., Berendt, F., Wagner, H., Heidenreich, S., Bauer, D., Welp, M., Cremer, T., 2023. Key actors' perspectives on agroforestry's potential in north eastern Germany. Land 12 (2), 458. https://doi.org/10.3390/land12020458.

Luick, R., 2009. Wood pastures in Germany. In: Rigueiro-Rodríguez, A., McAdam, J.H., Mosquera-Losada, M.R. (Eds.), Agroforestry in Europe. Advances in Agroforestry, sixth ed. Springer, Dordrecht, pp. 359–376. https://doi.org/10.1007/978-1-4020-8272-6_18.

Manning, P., Van Der Plas, F., Soliveres, S., Allan, E., Maestre, F.T., Mace, G., Whittingham, M.J., Fischer, M., 2018. Redefining ecosystem multifunctionality. Nat. Ecol. Evol. 2 (3), 427–436. https://doi.org/10.1038/s41559-017-0461-7.

Martin, P., Ruhl, J.B., 2023. Systems methods in non-doctrinal environmental law research. In: Martin, P., Teles da Silva, S., Leuzinger, M., Verbeek, M., Lawson, A. (Eds.), Non-doctrinal Research Methods in Environmental Law. Edward Elgar, Cheltenham, pp. 154–175.

Mauerhofer, V., 2018. The law, ecosystem services and ecosystem functions: an in-depth overview of coverage and interrelation. Ecosyst. Serv. 29, 190–198. https://doi.org/10.1016/j.ecoser.2017.05.011.

McGinnis, M.D., 2011. An introduction to IAD and the language of the Ostrom workshop: a simple guide to a complex framework. Policy Stud. J. 39 (1), 169–183. https://doi.org/10.1111/j.1541-0072.2010.00401.x.

McGinnis, M.D., Ostrom, E., 2014. Social-ecological system framework: initial changes and continuing challenges. Ecol. Soc. 19 (2), 30. https://doi.org/10.5751/ES-06387-190230.

Montgomery, I., Caruso, T., Reid, N., 2020. Hedgerows as ecosystems: service delivery, management, and restoration. Annu. Rev. Ecol. Evol. Syst. 51 (1), 81–102. https://doi.org/10.1146/annurev-ecolsys-012120-100346.

Morhart, C.D., Douglas, G.C., Dupraz, C., Graves, A.R., Nahm, M., Paris, P., Sauter, U.H., Sheppard, J., Spiecker, H., 2014. Alley coppice—a new system with ancient roots. Ann. For. Sci. 71 (5), 527–542. https://doi.org/10.1007/s13595-014-0373-5.

Mosquera-Losada, M.R., Santiago-Freijanes, J.J., Pisanelli, A., Rois-Díaz, M., Smith, J., den Herder, M., Moreno, G., Ferreiro-Domínguez, N., Malignier, N., Lamersdorf, N., Balaguer, F., Pantera, A., Rigueiro-Rodríguez, A., Aldrey, J.A., González-Hernández, M.P., Fernández-Lorenzo, J.L., Romero-Franco, R., Burgess, P.J., 2018. Agroforestry in the European common agricultural policy. Agroforest. Syst. 92 (4), 1117–1127. https://doi.org/10.1007/s10457-018-0251-5.

Mosquera-Losada, M.R., Santos, M.G.S., Gonçalves, B., Ferreiro-Domínguez, N., Castro, M., Rigueiro-Rodríguez, A., González-Hernández, M.P., Fernández-Lorenzo, J.L., Romero-Franco, R., Aldrey-Vázquez, J.A., Cabaleiro Sobrino, C., García-Berrios, J.J., Santiago-Freijanes, J.J., 2023. Policy challenges for agroforestry implementation in Europe. Front. For. Glob. Change 6, 1127601. https://doi.org/10.3389/ffgc.2023.1127601.

Mupepele, A.-C., Bruelheide, H., Brühl, C., Dauber, J., Fenske, M., Freibauer, A., Gerowitt, B., Krüß, A., Lakner, S., Plieninger, T., Potthast, T., Schlacke, S., Seppelt, R., Stützel, H., Weisser, W., Wägele, W., Böhning-Gaese, K., Klein, A.-M., 2021a. Biodiversity in European agricultural landscapes: transformative societal changes needed. Trends Ecol. Evol. 36 (12), 1067–1070. https://doi.org/10.1016/j.tree.2021.08.014.

Mupepele, A.-C., Keller, M., Dormann, C.F., 2021b. European agroforestry has no unequivocal effect on biodiversity: a time-cumulative meta-analysis. BMC Ecol. Evol. 21 (1) https://doi.org/10.1186/s12862-021-01911-9.

Ndlovu, N.P., Borrass, L., 2021. Promises and potentials do not grow trees and crops. A review of institutional and policy research in agroforestry for the Southern African region. Land Use Pol. 103, 105298 https://doi.org/10.1016/j.landusepol.2021.105298.

Nerlich, K., Graeff-Hönninger, S., Claupein, W., 2013. Agroforestry in Europe: a review of the disappearance of traditional systems and development of modern agroforestry practices, with emphasis on experiences in Germany. Agroforest. Syst. 87 (2), 475–492. https://doi.org/10.1007/s10457-012-9560-2.

Öllerer, K., Varga, A., Kirby, K., Demeter, L., Biró, M., Bölöni, J., Molnár, Z., 2019. Beyond the obvious impact of domestic livestock grazing on temperate forest vegetation – a global review. Biol. Conserv. 237, 209–219. https://doi.org/10.1016/j.biocon.2019.07.007.

Ostrom, E., 2009. A general framework for analyzing sustainability of social-ecological systems. Science 325 (5939), 419–422. https://doi.org/10.1126/science.1172133.

Partelow, S., 2018. A review of the social-ecological systems framework: applications, methods, modifications, and challenges. Ecol. Soc. 23 (4), 36. https://doi.org/10.5751/ES-10594-230436.

Pe'er, G., Dicks, L.V., Visconti, P., Arlettaz, R., Báldi, A., Benton, T.G., Collins, S., Dieterich, M., Gregory, R.D., Hartig, F., Henle, K., Hobson, P.R., Kleijn, D., Neumann, R.K., Robijns, T., Schmidt, J., Shwartz, A., Sutherland, W.J., Turbé, A., Wulf, F., Scott, A.V., 2014. EU agricultural reform fails on biodiversity. Science 344 (6188), 1090–1092. https://doi.org/10.1126/science.1253425.

Pe'er, G., Zinngrebe, Y., Hauck, J., Schindler, S., Dittrich, A., Zingg, S., Tscharntke, T., Oppermann, R., Sutcliffe, L., Sirami, C., Schmidt, J., Hoyer, C., Schleyer, C., Lakner, S., 2017. Adding some green to the greening: improving the EU's ecological focus areas for biodiversity and farmers. Conserv. Lett. 10 (5), 517–530. https://doi.org/10.1111/conl.12333.

Pe'er, G., Bonn, A., Bruelheide, H., Dieker, P., Eisenhauer, N., Feindt, P.H., Hagedorn, G., Hansjürgens, B., Herzon, I., Lomba, Â., Marquard, E., Moreira, F., Nitsch, H., Oppermann, R., Perino, A., Röder, N., Schleyer, C., Schindler, S., Wolf, C., Zinngrebe, Y., Lakner, S., 2020. Action needed for the EU Common Agricultural Policy to address sustainability challenges. People Nat 2 (2), 305–316. https://doi.org/10.1002/pan3.10080.

Plieninger, T., Höchtl, F., Spek, T., 2006. Traditional land-use and nature conservation in European rural landscapes. Environ Sci Policy 9 (4), 317–321. https://doi.org/10.1016/j.envsci.2006.03.001.

Plieninger, T., 2011. Capitalizing on the carbon sequestration potential of agroforestry in Germany's agricultural landscapes: realigning the climate change mitigation and landscape conservation agendas. Landsc. Res. 36 (4), 435–454. https://doi.org/10.1080/01426397.2011.582943.

Plieninger, T., Levers, C., Mantel, M., Costa, A., Schaich, H., Kuemmerle, T., 2015. Patterns and drivers of scattered tree loss in agricultural landscapes: orchard meadows in Germany (1968-2009). PLoS One 10 (5), e0126178. https://doi.org/10.1371/journal.pone.0126178.

Prip, C., 2018. The Convention on Biological Diversity as a legal framework for safeguarding ecosystem services. Ecosyst. Serv. 29, 199–204. https://doi.org/10.1016/j.ecoser.2017.02.015.

Quinkenstein, A., Wöllecke, J., Böhm, C., Grünewald, H., Freese, D., Schneider, B.U., Hüttl, R.F., 2009. Ecological benefits of the alley cropping agroforestry system in sensitive regions of Europe. Environ. Sci. Policy 12 (8), 1112–1121. https://doi.org/10.1016/j.envsci.2009.08.008.

Ramsauer, U., 2024. Allgemeines umweltverwaltungsrecht. In: Koch, H.J., Hofmann, E., Reese, M. (Eds.), Handbuch Umweltrecht. C. H. Beck, München, pp. 145–238.

Rodríguez, J.P., Beard Jr, T.D., Bennett, E.M., Cumming, G.S., Cork, S.J., Agard, J., Dobson, A.P., Peterson, G.D., 2006. Trade-offs across space, time, and ecosystem services. Ecol. Soc. 11 (1), 28. http://www.ecologyandsociety.org/vol11/iss1/art28/.

Santiago-Freijanes, J.J., Rigueiro-Rodríguez, A., Aldrey, J.A., Moreno, G., den Herder, M., Burgess, P., Mosquera-Losada, M.R., 2018. Understanding agroforestry

practices in Europe through landscape features policy promotion. Agroforest. Syst. 92 (4), 1105–1115. https://doi.org/10.1007/s10457-018-0212-z.
Santiago-Freijanes, J.J., Mosquera-Losada, M.R., Rois-Díaz, M., Ferreiro-Domínguez, N., Pantera, A., Aldrey, J.A., Rigueiro-Rodríguez, A., 2021. Global and European policies to foster agricultural sustainability: agroforestry. Agroforest. Syst. 95 (5), 775–790. https://doi.org/10.1007/s10457-018-0215-9.
Simelton, E.S., Catacutan, D.C., Dao, T.C., Dam, B.V., Le, T.D., 2017. Factors constraining and enabling agroforestry adoption in Viet Nam: a multi-level policy analysis. Agroforest. Syst. 91, 51–67. https://doi.org/10.1007/s10457-016-9906-2.
Torralba, M., Fagerholm, N., Burgess, P.J., Moreno, G., Plieninger, T., 2016. Do European agroforestry systems enhance biodiversity and ecosystem services? A meta-analysis. Agric. Ecosyst. Environ. 230, 150–161. https://doi.org/10.1016/j.agee.2016.06.002.
Torralba, M., Fagerholm, N., Hartel, T., Moreno, G., Plieninger, T., 2018. A social-ecological analysis of ecosystem services supply and trade-offs in European wood-pastures. Sci. Adv. 4 (5), eaar2176 https://doi.org/10.1126/sciadv.aar2176.
Tsonkova, P., Böhm, C., Quinkenstein, A., Freese, D., 2012. Ecological benefits provided by alley cropping systems for production of woody biomass in the temperate region: a review. Agroforest. Syst. 85 (1), 133–152. https://doi.org/10.1007/s10457-012-9494-8.
Tsonkova, P., Mirck, J., Böhm, C., Fütz, B., 2018. Addressing farmer-perceptions and legal constraints to promote agroforestry in Germany. Agroforest. Off. Syst. 92 (4), 1091–1103. https://doi.org/10.1007/s10457-018-0228-4.
Veldkamp, E., Schmidt, M., Markwitz, C., Beule, L., Beuschel, R., Biertümpfel, A., Bischel, X., Duan, X., Gerjets, R., Göbel, L., Graß, R., Guerra, V., Heinlein, F., Komainda, M., Langhof, M., Luo, J., Potthoff, M., van Ramshorst, J.G.V., Rudolf, C., Seserman, D.-M., Shao, G., Siebicke, L., Svoboda, N., Swieter, A., Carminati, A., Freese, D., Graf, T., Greef, J.M., Isselstein, J., Jansen, M., Karlovsky, P., Knohl, A., Lamersdorf, N., Priesack, E., Wachendorf, C., Wachendorf, M., Corre, M.D., 2023. Multifunctionality of temperate alley-cropping agroforestry outperforms open cropland and grassland. Commun. Earth Environ 4 (1), 20. https://doi.org/10.1038/s43247-023-00680-1.
VG Hannover, 2022. Naturschutzrechtliche Wiederherstellungsanordnung; Beseitigung von Lebensstätten wild lebender Tiere und Pflanzen judgement of 11 July 2022 - 12 A 2491/18, juris.
Weller, F., 2014. Streuobstwiesen. In: Konold, W., Böcker, R., Hampicke, U. (Eds.), Handbuch Naturschutz und Landschaftspflege. VCH Whiley, pp. 1–42. https://doi.org/10.1002/9783527678471.hbnl2006001.