Received: 17 June 2024 | Accepted: 21 June 2025

DOI: 10.1002/pan3.70103

BRITISH ECOLOGICAL SOCIETY | People and Nature

RESEARCH ARTICLE

Pathways for biodiversity enhancement in German agricultural landscapes

Christian Sponagel[1] | Amibeth Thompson[2] | Hubertus Paetow[3] | Anne-Christine Mupepele[4] | Claudia Bieling[5] | Martin Sommer[6] | Alexandra-Maria Klein[2] | Josef Settele[7,8] | Robert Finger[9] | Robert Huber[9] | Christian Albert[10] | Juliane Filser[11] | Florian Jansen[12] | Janina Kleemann[7,13] | Vera Schreiner[13] | Sebastian Lakner[12]

[1]Department of Farm Management, University of Hohenheim, Stuttgart, Germany; [2]Nature Conservation and Landscape Ecology, University of Freiburg, Freiburg, Germany; [3]DLG e.V.—German Agricultural Society, Frankfurt am Main, Germany; [4]Department of Biology—Animal Ecology, University of Marburg, Marburg, Germany; [5]Department of Societal Transition and Agriculture, University of Hohenheim, Stuttgart, Germany; [6]Deutscher Verband für Landschaftspflege (DVL)—Landcare Germany, Ansbach, Germany; [7]German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Leipzig, Germany; [8]Helmholtz-Centre for Environmental Research—UFZ, Halle, Germany; [9]Agricultural Economics and Policy, ETH Zürich, Zürich, Switzerland; [10]Institute of Environmental Planning, Leibniz University Hannover, Hannover, Germany; [11]Center for Environmental Research and Sustainable Technology (UFT), University of Bremen, Bremen, Germany; [12]Faculty of Agricultural and Environmental Sciences, University of Rostock, Rostock, Germany and [13]Department of Sustainable Landscape Development, Institute for Geosciences and Geography, Martin-Luther University Halle-Wittenberg, Halle, Germany

Correspondence
Christian Sponagel
Email: christian.sponagel@uni-hohenheim.de

Funding information
Bundesministerium für Bildung und Forschung, Grant/Award Number: 16LC2001B and 16LC2001F

Handling Editor: Emmeline Topp

Abstract

1. Conserving biodiversity, especially in agricultural landscapes, is a major societal challenge. Broad scientific evidence exists on the impacts of single drivers on biodiversity, such as the intensification of agriculture. However, halting biodiversity decline requires a systemic understanding of the interactions between multiple drivers, which has hardly been achieved so far. Selecting Germany as a case study, the goal of our analysis is (i) to understand how various socio-economic drivers of biodiversity in agricultural landscapes interact at the national scale, (ii) to identify plausible pathways that most likely will lead to an improvement of biodiversity in agricultural landscapes and (iii) to discuss guiding principles for policy-making based on the pathways.
2. We applied the expert-based Cross-Impact-Balance (CIB) methodology to the German agri-food system (target year 2030). Seven descriptors that represent the most relevant socio-economic drivers of biodiversity (here, we focus on species richness) in agricultural landscapes in Germany were defined. In three workshops with different groups of experts, we assessed all the interactions and impacts between these descriptors. From the workshops, seven overlapping scenarios were identified and aggregated into four main future pathways for enhancing biodiversity in agricultural landscapes.

3. These pathways are: (1) 'Innovation and stricter legislation', (2) 'Major change in protein production and CAP shift', (3) 'Major change in protein production and national legislation' and (4) 'Major social changes compensate for a lack of innovation in food production'.
4. Socio-economic drivers interact to varying degrees. Societal values have a strong active influence on the system, e. g. agricultural policy, whereas the orientation and objectives of agriculture, e. g. focus on public goods, are rather passively determined. Conserving biodiversity thus depends upon the evolution of societal values, European and national nature conservation and agricultural policies, innovations in plant and protein production as well as on global commodity markets.
5. A key message for policymakers is that there are generally different, complementary options for achieving the objective of improving biodiversity. This is important when specific drivers such as the CAP cannot be steered in a particular desired direction.

KEYWORDS
agricultural landscape, biodiversity, biodiversity-enhancing scenarios, Cross-Impact-Balance analysis, future pathways, Germany

1 | INTRODUCTION

1.1 | Biodiversity loss in agricultural landscapes at global and local scales

Globally, current agricultural intensification is a major driver of biodiversity loss (Beaumelle et al., 2023; Campbell et al., 2017; IPBES, 2019; Kehoe et al., 2017). Unsustainable agricultural practices with a high input use of fertilizers and pesticides beyond ecological carrying capacities, the overuse of soil without regeneration, deforestation, monotonous crops, among others, have globally led to ecosystem degradation and loss in biodiversity. Similar to European trends, agricultural landscapes and other ecosystems in Germany are facing a tremendous decline in biodiversity, in particular habitat loss, declining populations and species numbers (BfN, 2023; Hallmann et al., 2017, 2021; Kamp et al., 2021; Rigal et al., 2023; Seibold et al., 2019; Skarbek et al., 2021; Wirth, Bruelheide, Farwig, Marx, & Settele, 2024).

1.2 | Why policy targets on biodiversity have not been achieved

Despite international and national targets that have been set and updated for over two decades, such as the Convention on Biological Diversity (CBD, 1992) or the German Strategy on Biological Diversity (BMU, 2007), biodiversity has thus continued to drastically decline, demonstrating that the actions are insufficient. The reason for this failure is that these politically agreed targets do not specifically propose in-depth actions for fundamental change (transformation) and hardly address indirect drivers such as economic and technological developments (Chan et al., 2020; IPBES, 2019). The concept of drivers is widely used in land use change research (Bürgi et al., 2005; Plieninger et al., 2016; Van Vliet et al., 2015). The aim is to understand the underlying reasons or driving forces for land use change (Bürgi et al., 2005). Plieninger et al. (2016) speak of proximate and underlying drivers, which have a more indirect effect on land use change and underlie the proximate or direct drivers. System knowledge, that is, how a system works, is gained by understanding the drivers in a system (Pohl & Hirsch Hadorn, 2007). Indirect drivers (e. g. policy, legislation and societal values) play a central role in the concepts of *leverages* and *levers* for transformation towards sustainability as they relate to the root causes of human interactions with nature (Abson et al., 2017; Fischer & Riechers, 2019). The leverage points can be classified from shallow to deep, that is, deeper points of intervention in the system, such as values or world views actors in a system have a higher transformative impact but are much more difficult to address through policy measures, for example (Abson et al., 2017). Levers like economic or agricultural policies can affect key points for intervention such as more environmentally friendly management practices through innovative technologies (Chan et al., 2020; Díaz, Demissew, Carabias, et al., 2015; IPBES, 2019). Another lever for a sustainable agri-food system would be a movement of social values in favour of practices that are more respectful of the environment (Chan et al., 2020; McGreevy et al., 2022). Consequently, indirect drivers should be given priority over direct drivers that affect nature directly (e. g. pesticide use or habitat loss) when analysing future transformation scenarios on biodiversity in the agricultural landscape (Díaz, Demissew, Joly, et al., 2015; Klein et al., 2024).

1.3 | How agri-food systems are shaping biodiversity

The agricultural landscapes with their biodiversity are shaped by agri-food systems which include the primary agricultural production, food distribution and consumption as well as inputs such as synthetic fertilizers or pesticides (Crenna et al., 2019; FAO, 2021; Sims et al., 2015). Within agri-food systems, there are many indirect and direct drivers of change that also affect biodiversity in agricultural landscapes (Thompson & Scoones, 2009). Here we focus on socio-economic drivers as indirect or underlying drivers (Plieninger et al., 2016). Socio-economic drivers are related to human decisions and include political-legal, economic-technological and social framework conditions and developments (Klein et al., 2024; Mupepele et al., 2019). In the agricultural landscape, many societal interests and demands for different ecosystem services come together and must be carefully balanced (Coupe et al., 2012). Beyond potential synergies in the context of multifunctional land use, there are often trade-offs (Galler et al., 2015; Samnegård et al., 2019). For example, trade-offs exist between agricultural production and land consumption for infrastructure development or renewable energies (Unger & Lakes, 2023), or between agricultural production and environmental protection. For instance, water pollution can be a consequence of agricultural production by high fertilizer use (Flörke et al., 2018; Weik et al., 2022). As all these land use interests compete for the same land plots, there are strong interactions which must, therefore, be considered within agri-food systems (Thompson & Scoones, 2009).

1.4 | Importance of scenarios and pathways for steering agri-food systems in the future

Whereas scenarios can be understood as plausible possible future states, pathways aim at specific scenarios with certain desired target states that can also be supported by respective narratives (IPBES, 2019; Leach, Scoones, & Stirling, 2010; Zurek & Henrichs, 2007). Both scenarios and pathways depict potential future states and are therefore valuable for supporting decision-making processes by policymakers, such as steering agri-food systems to be more biodiversity-friendly (Mitter et al., 2020). In this respect, they provide the required transformation knowledge on how a certain policy target can be achieved (Pohl & Hirsch Hadorn, 2007). The pathways approach can advance our understanding of human-nature relationships by showing different alternatives of how human activities may or may not be consistent with achieving sustainability goals. This is also relevant and applicable for dealing with environmental management conflicts and controversial perspectives between different societal actors (Beland Lindahl et al., 2016).

Many scenario analyses in agri-food systems exist on the interaction between biodiversity and selected drivers, such as urbanization (Di Pirro et al., 2021; Simkin et al., 2022), economic growth (Otero et al., 2020), agricultural management intensity (Jeanneret et al., 2021; Kleijn et al., 2009; Zabel et al., 2019), as well as socio-economic scenarios on a global scale considering consumption, access to food, waste, agricultural productivity, protected areas and forestry (Visconti et al., 2016). Still, research gaps remain. First, to gain more advanced system knowledge (Pohl & Hirsch Hadorn, 2007), it is not enough to look only at specific isolated interactions between indirect drivers of a system, but a more holistic perspective is required to tackle biodiversity loss (Jaureguiberry et al., 2022). Second, the studies mentioned above did not explicitly focus on the agricultural landscape and thus neglected the role of agricultural policies like the Common Agricultural Policy (CAP) or innovations in agricultural production. Third, scenarios on biodiversity at the global level often pose challenges when it comes to transferring them to the local level, for example, due to cultural differences or insufficient spatial resolution of regional land use (IPBES, 2019; Rosa et al., 2020).

Consequently, pathways need to be developed for enhancing biodiversity in agricultural landscapes that provide system and transformation knowledge at the national or local level, from which concrete policy measures can be directly derived, while also accounting for global developments and the relationship between biodiversity and different socio-economic policy objectives (Hermoso et al., 2022; Perino et al., 2022). This is important because the translation of policy objectives into concrete actions can be a challenge (Boix-Fayos & De Vente, 2023; Perino et al., 2022).

In the literature on transformation, the concept of pathways often serves to explore how defined sustainability goals can be achieved (IPBES, 2019; Rosenbloom, 2017). In line with this, we understand pathways as a set of potential future changes in agri-food systems that lead to the politically desired outcome to enhance biodiversity, that is, defining in which direction agri-food systems need to evolve over time (Leach, Stirling, & Scoones, 2010). In this context and in this study, pathways represent plausible future states (scenarios) achieving a specified target with a focus on the required actions to get there (Aguiar et al., 2020; Van Vuuren et al., 2012).

The goal of our analysis is to (i) understand how different socio-economic indirect drivers (=descriptors) of biodiversity in agricultural landscapes interact at the national scale, (ii) derive plausible pathways that most likely will lead to an improvement of biodiversity in the agricultural landscapes and (iii) discuss guiding principles for policy-making based on the pathways.

As outlined above, current pathway developments in this area have missed the interaction between multiple drivers. We adopted a more holistic and systematic approach: The novelty of our study lies in the focus on the interaction between multiple socio-economic drivers of biodiversity in agricultural landscapes during pathway development. Using a new conceptual framework, we applied the

Cross-Impact-Balance (CIB) methodology as a qualitative yet systematic approach which integrates interdisciplinary expertise and investigates any interactions between drivers in a formalized process. By presenting and applying this framework through the CIB methodology to a specific case study, Germany, our study makes a novel contribution to the literature on drivers of biodiversity loss and pathways for improving biodiversity in agricultural landscapes. To the best of our knowledge there is no comparable study that focused on the interactions and impacts between multiple socio-economic drivers of biodiversity in agricultural landscapes, using the example of Germany.

In the following, we first give a brief description of the study region, then we introduce the methodological approach of the Cross-Impact-Balance analysis as a structured qualitative scenario development tool. From the results, we derive guiding principles for policy-making.

2 | MATERIALS AND METHODS

2.1 | Description of the case study region

Germany was selected as a case study for three reasons: It is a major agricultural producer in terms of output value and production volume for many crops like cereals, oilseeds or sugar beet in the European Union, and arable land use in general is characterized by a comparatively high management intensity (Eurostat, 2024a, 2024b; Rega et al., 2020; Silva et al., 2019), accompanied by a substantial accumulation of pesticides even in non-crop areas (Brühl et al., 2024). Furthermore, Germany is facing high biodiversity loss, especially in agricultural systems (Wirth, Bruelheide, Farwig, & Marx, 2024). Against this backdrop, the trade-offs between agricultural production and the promotion of biodiversity become particularly clear in this country. At the same time, although Germany has implemented various policies and initiatives aimed at promoting biodiversity in agricultural landscapes such as agri-environmental measures or biosphere reserves, a persistent biodiversity decline in agricultural landscapes can be observed (Klein et al., 2024).

The development of biodiversity in the agricultural landscape of Germany has been influenced by various factors and framework conditions. Historically, traditional agricultural practices tended to support higher levels of biodiversity through mixed cropping, rotational grazing and diverse landscape features such as hedgerows and small woodlots (Assandri et al., 2018; Špulerová et al., 2018). However, the intensification of agriculture in the 20th century as a direct driver has led to widespread habitat loss, monoculture farming, large fields and increased use of pesticides and fertilizers, resulting in a significant decline in biodiversity also in Germany (Nationale Akademie der Wissenschaften Leopoldina et al., 2020; Rigal et al., 2023). Today, agricultural land encompasses over 50% of the entire area of Germany, with 70% of it dedicated to arable farming (BMEL, 2022). Only 13.4% of this area can be categorized as having High-Nature-Value (BfN, 2023). Likewise, about 69% of open habitats in Germany are endangered, including half of the arable fields and fallow biotopes (BfN, 2017). Through monitoring programmes, it is possible to assess the status and trends of the habitats, along with the plant and animal communities in these areas. On average, the majority of trends that have monitored species richness and abundances of plants and animals in German agricultural landscapes have observed no change over the last century (Klein et al., 2024). Rather, there have been sharp declines in species richness and abundances for specific groups, such as arable weed species, various insect groups (e. g., butterflies, grasshoppers and hoverflies) and farmland birds (Klein et al., 2024; Nationale Akademie der Wissenschaften Leopoldina et al., 2020).

2.2 | Cross-impact-balance analysis

In order to assess the interaction between socio-economic drivers as descriptors of biodiversity in the agricultural landscape in Germany and to identify pathways to enhance biodiversity, we chose the Cross-Impact-Balance (CIB) analysis methodology (Weimer-Jehle, 2006). The CIB is a structured qualitative method for analysing systems and deriving future scenarios (Figure 1) (Weimer-Jehle, 2006). These future scenarios are based on the most relevant descriptors of a system and their potential developments, which are defined as trend alternatives (details in Sections 2.3 and 2.4 and Appendix S1). Experts from different disciplines and sectors are invited to qualitatively assess the influence relationships between individual descriptors and their future trend alternatives (details in Section 2.5 and Appendix S2). The final aim of the analysis is to identify consistent future scenarios in the form of plausible combinations with regard to the development of the system descriptors (details in Section 2.6). More details and information on the methodology can be found in Weimer-Jehle (2023a).

2.3 | Literature review and identification of descriptors used in the cross-impact-balance analysis

The CIB analysis was an outsourced scientific activity of the project 'Faktencheck Artenvielfalt' or 'German Biodiversity Assessment[1]' (Wirth, Bruelheide, Farwig, Marx, & Settele, 2024), in particular of the working group for the chapter 'Agricultural and open landscapes'. The German Biodiversity Assessment reports on the status, trends and drivers of biodiversity in Germany. As part of this project, a comprehensive literature review was conducted on the most relevant drivers (direct and indirect) of biodiversity in German agricultural landscapes within the agri-food system. Drivers were categorized as being direct or indirect according to the classifications provided by the

[1]'Faktencheck Artenvielfalt' (German Biodiversity Assessment) is a joint project involving over 150 authors from various institutes that aims to create a national assessment of biodiversity in Germany. It is funded by the German Federal Ministry of Education and Research (BMBF) as part of the Research Initiative for the Conservation of Biodiversity (FEdA) and was published in October 2024.

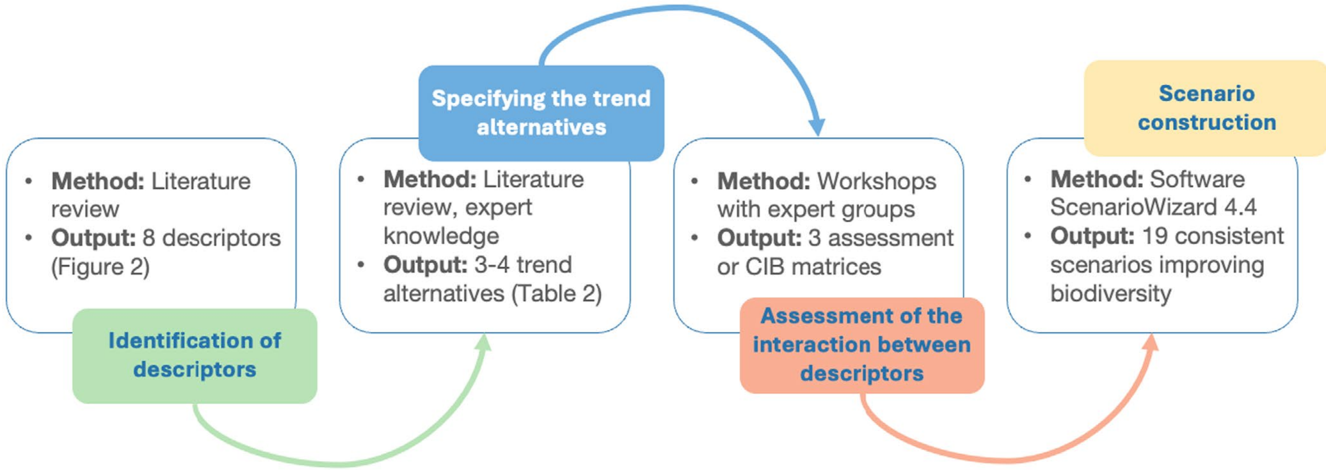

FIGURE 1 Graphic representation of the Cross-Impact-Balance (CIB) analysis methodology with its different elements or methods applied in this study.

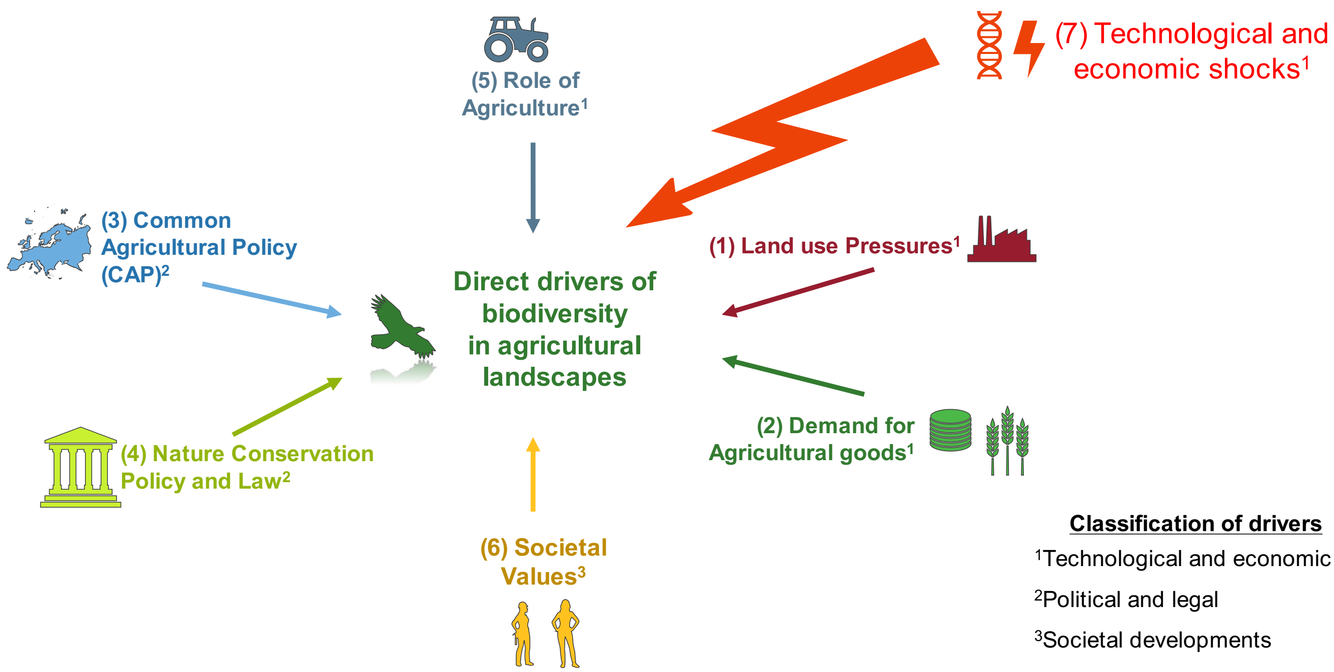

FIGURE 2 Economic and social drivers for biodiversity in the agricultural landscape (conceptual framework) with links between indirect drivers (indicated by the dashed arrows) and links between indirect and direct drivers in the middle (indicated by the solid arrows).

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019). We used the results of the literature review from the German Biodiversity Assessment on indirect drivers and respective internal discussions in the chapter group as a starting point for the CIB analysis to define the descriptors and their respective trend alternatives. The CIB descriptors were thus based on the most relevant socio-economic drivers for biodiversity in the agricultural landscape and can be classified according the framework of the German Biodiversity Assessment into (a) political and legal, (b) technological and economic as well as (c) societal developments (Klein et al., 2024; Wirth, Bruelheide, Farwig, Marx, & Settele, 2024). Finally, seven socio-economic drivers were selected for consideration as CIB descriptors in the scenario analysis, which form our conceptual framework for the development of the pathways (Figure 2).

The first descriptor is land use pressure (1) (Table 1), which represents the level of land scarcity and covers the uptake of agricultural land for settlement, infrastructure, renewable energies, nature conservation as well as rewetting of peatlands (Osterburg et al., 2023). As a second descriptor, the demand for agricultural products (2) was chosen to consider the interactions between agricultural production and the national or global market (Haß et al., 2022). Moreover, policy instruments like the CAP (3) as well as national nature conservation policy and law were included. The CAP can be regarded as one of the most relevant policy instruments on EU as well as national level

TABLE 1 Overview and brief description of the descriptors and their respective trend alternatives for the agri-food systems in Germany (scenarios for the target year 2030).

Descriptor	Trend alternative	Brief description
A. Land use pressures	A1. Strong increase in land use pressures	Decrease in agricultural land in the range up to 5% by 2030 compared to 2022, because of increasing competition between land use interests
	A2. Moderately sustained land use pressures (BAU)	Decrease in agricultural land in the range up to 2% by 2030 compared to 2022
	A3. Decrease in land use pressures	Decrease in agricultural land in the range of up to 1% by 2030 compared to 2022
B. Demand for agricultural goods	B1. Stable supply situation	A stable supply situation at the global market and decreasing domestic demand
	B2. Thünen Baseline 2032 (BAU)	The demand for agricultural products remains globally on current level, whereas domestic demand for meat decreases by about 10%
	B3. Global food crisis	Strong increase in the global population as well as bad regional harvests and high world market prices for agricultural goods
C. Common Agricultural Policy (CAP)	C1. Loss of importance of the CAP	The financial and substantive role of the CAP will decline significantly by 2030. In 2034, the CAP will still account for 15% of the EU budget
	C2. Update of the current CAP (BAU)	Current development of the CAP, such as the stronger environmental focus, is continuing with moderately decreasing financial resources
	C3. Focus on environmental performance	The focus of the CAP is on public goods. The financial budget remains at the current level
D. Nature conservation policy and law	D1. Strong legal tightening	Strong increase in regulatory law for pesticide use and interventions in ecosystems, for instance from urban development
	D2. Moderate legal tightening (BAU)	Slight tightening of regulatory requirements. Achievement of the farm-to-fork strategy goals regarding pesticide reduction
	D3. Market-oriented nature conservation	Nature conservation at the retail point via marketing and compensation instruments instead of legal tightening
	D4. Withdrawal of the state from nature conservation policy	No new legal requirements and implementation deficits in nature conservation as well as a lack of framework conditions for market-orientated nature conservation
E. Societal values	E1. Sustainability and post-materialism	Nature conservation is gaining in importance in public perception and also shapes consumer behaviour (e.g. lower meat consumption, higher use of regional products)
	E2. Continuation of social complexity (BAU)	There is no consensus on the environmental policy direction within society
	E3. Dominance of materialism	Consumer decisions are price-orientated and material things have priority
F. Biodiversity in agricultural landscapes	F1. Improvement	Recovery of populations of many species at all taxonomic levels
	F2. Constant (BAU)	No further decline of biodiversity; biodiversity status quo
	F3. Deterioration	The drastic decline of biodiversity until 2030
G. Role of agriculture	G1. Extensification and public goods	Extensification of agricultural production in favour of other ecosystem services and provision of public goods
	G2. Business-as-usual (BAU)	The type and extent of land utilization continues in the current productivity, with a slight decline in the use of inputs
	G3. Intensification of production	Intensification of production with increasing use of inputs per unit area. There is hardly any extensive land utilization
H. Technological and economic developments 'shocks'	H1. Innovations in plant production	Indoor farming will be of considerable importance by 2030. Yield increases through the use of new breeding technologies (NBTs)
	H2. Innovations in protein production	In 2030, cellular meat will have established itself on the market and will replace approx. 25% of the protein from meat
	H3. National economic slump	Industry in Germany is losing its competitiveness in the long term. The resources of the state budget are limited
	H4. Global recession	There are temporary regional economic crises and disruption to international supply chains

Note: One trend alternative of each descriptor represents a business-as-usual development (BAU) (source: own presentation).

to foster sustainable agricultural production. Typical CAP policy measures comprise regulation of agricultural management practices, economic instruments like subsidies or information and education (Möhring et al., 2020). In addition, national regulatory law (4) has a considerable influence on the type of land use. This includes, for example, instruments for the protection of areas (e.g. Habitats Directive and nature conservation areas) (Hering et al., 2023), minimum requirements for agriculture (e.g. Fertilizer Ordinance, Plant Protection Act), the approval of pesticides, but also regulations on biodiversity offsets in terms of settlement and infrastructure development (Mupepele et al., 2021). In addition, the role of agriculture for preserving biodiversity (5) was included as a descriptor. The role of agriculture refers to the paradigms of agricultural production in terms of the general orientation or role assigned to it within society. It therefore includes also aspects of structural change and ongoing transformations: for example, a stronger focus on the provision of multiple ecosystem services or a high transformation pressure towards the intensification of biomass production. The role of agriculture referring to the objectives and preferences of the actors in the sector can thus be regarded as an indirect driver. For details see Appendix S1. Societal values (6) form the framework for the population's attitude towards nature and species conservation. These values largely determine people's behaviour and therefore also their consumption decisions for or against sustainable food products (Bieling et al., 2020; Mupepele et al., 2021). Hence, they were also included as indirect drivers. As we are analysing future scenarios, developments that are unlikely or uncertain from today's perspective, but which may have disruptive effects on agri-food systems and thus foster change, are also relevant (Meuwissen et al., 2019). Hamilton et al. (2020) identified together with stakeholders four potential future shocks to global agri-food systems within the next 25 years: technological, financial, climatic and biological shocks. As we focus on the socio-economic drivers of biodiversity, we therefore included technological and economic shocks (7) in the analysis, for instance, innovations in plant production including new plant breeding technologies (NBTs) (Qaim, 2020). The selected descriptors are also in line with other literature sources on the main drivers of biodiversity loss (IPBES, 2019; Nationale Akademie der Wissenschaften Leopoldina et al., 2020). In contrast to IPBES (2019), we did not explicitly include conflicts and wars as geopolitical crises or health problems such as epidemics. However, these aspects are implicitly covered by the potential future development options of respective descriptors like the global demand for agricultural goods.

In a next step, potential future development alternatives regarding the descriptors were derived, which will be explained in more detail in the following section.

2.4 | CIB descriptors and their respective trend alternatives

The socio-economic drivers identified in Section 2.3 represent seven descriptors related to the most relevant indirect drivers of biodiversity in German agricultural landscapes within the agri-food system. According to the focus of the analysis we included the development of biodiversity as a dependent descriptor. This means that biodiversity absorbs the influences of the other descriptors, but does not itself influence them. For each of the eight descriptors, three to four trend alternatives were derived (Table 1) based on literature and expert knowledge generated in the 'Faktencheck Artenvielfalt' project (Klein et al., 2024). These trend alternatives were derived in such a way that there was usually an intermediate alternative, representing a continuation of the status quo and two 'extreme' changes in opposite directions, representing a deviation from the status quo. Our target year for the definition of trend alternatives and developing pathways was 2030.

In each case, one trend alternative was related to the continuation of the status quo, that is, business-as-usual (BAU). The others were defined in such a way that they contrast with each other, for instance a stable supply situation at the global market (B1) and global food crisis (B3) in terms of demand for agricultural products. Table 1 provides an overview of the descriptors with their trend alternatives and a brief description of them. A more detailed explanation of the descriptors and the associated trend alternatives as well as the considered literature can be found in Appendix S1.

2.5 | Assessment of the interaction between descriptors

The assessment of the interaction between the descriptors and their respective trend alternatives was carried out between April and June 2023 as part of three workshops lasting around three to 4 h with experts from the fields of nature conservation and agricultural sciences who work either in academia or in practice in Germany (Table 2). Twenty experts were selected and invited via email by the Faktencheck Artenvielfalt project, all of whom were known by members of the agricultural and open landscapes working group to be actively working at the interface of agriculture and biodiversity and to have in-depth knowledge in this area. Six agreed and attended the workshop. Three suggested colleagues to us who also agreed and attended. The different workshops allowed a comparison across group results and to identify overlapping scenarios. The first workshop was conducted with eight people from nature conservation and agricultural sciences (mixed group). The second workshop was held with a group of four people from nature conservation (nature conservation group) and the third workshop was conducted with a group of eight people from agricultural sciences (agricultural group).

For the interpretation of the results, it is important to reflect on the positionality of the represented experts. For instance, the expert for agronomy in the agricultural group represented an internationally operating NGO in the field of nature and environmental protection, but with a focus on German agriculture and thus a wide spectrum of different farm types and farming practices. In the mixed group the expert from the agricultural NGO represented a German NGO that focuses on knowledge transfer from science to practical

TABLE 2 Detailed overview of the disciplinary background and type of experts that participated in the three workshops.

Workshop group	Disciplinary background	Type	Amount of representatives
Mixed group ($n=8$)	Agricultural economics	Academic staff at universities or research centers	1
	Landscape ecology	Academic staff at universities or research centers	3
	Agricultural economics	Agricultural NGO	1
	Biology	Environmental NGO	1
	Biology	Academic staff at universities or research centers	1
	Social science in agriculture	Academic staff at universities or research centers	1
Nature conservation ($n=4$)	Vegetation ecology	Academic staff at universities or research centers	1
	Environmental science	Academic staff at universities or research centers	3
Agriculture ($n=8$)	Agricultural economics	Academic staff at universities or research centers	4
	Agricultural markets and policies	Academic staff at universities or research centers	3
	Agronomy	NGO	1

farming and the experts from the environmental NGO represented a German organization that mainly operates at the national level, for example, implementing model projects and aims to connect agriculture, forestry, nature conservation and policy. The representatives of science were selected because they have a strong research focus on biodiversity conservation in the context of transformations of agri-food systems such as pesticide-free agriculture or development of the Common Agricultural Policy, either from an economic or nature conservation perspective.

The three workshops were organized in the form of moderated group discussions (O.Nyumba et al., 2018). Two researchers were present to moderate and document the workshops. All data was collected in an Excel spreadsheet, which was shared with participants during the workshops. At the beginning of the workshop, all participants gave their verbal consent to voluntary participation and to the anonymized processing of their statements and the publication of the results.

Each individual interaction between two trend alternatives of the respective descriptors was discussed in turn. Participants were given the opportunity to speak and give a reasoned judgement on a semi-quantitative scale: 'favourable' (1), 'inhibiting' (−1) or 'neutral or everything is plausible' (0). Counter-arguments for alternative assessment proposals could then be provided by the other participants (Figure 3). This was repeated until a consensus was reached. The next interaction was then discussed in the same way. As a result, three assessment or cross-impact-matrices were generated that are given in Appendix S2.

2.6 | Deriving consistent scenarios and associated pathways

The three assessment matrices generated during the expert workshops were now analysed separately for each group with the software ScenarioWizard 4.4 (Weimer-Jehle, 2023b) in order to identify consistent scenarios. For this purpose, the descriptors and trend alternatives were defined in the software and the ratings entered in table form. In total, 14,580 combinations of descriptors and respective trend alternatives would have been possible in one assessment matrix and were proofed for consistency by the respective software algorithm as explained below.

Ideally, a fully consistent scenario would always refer to the trend alternatives with the highest impact balance for all descriptors. There are therefore no contradictory influencing relationships between the trend alternatives in a consistent scenario; ideally, there are mutually supporting relationships. This is not the case in the example in Figure 4, as the impact balance for descriptor A (Land use pressures) is not highest for alternative A3 (−1), but for alternative A1 (+1). Also, for descriptor C (CAP), the impact balance is negative (−1). In this respect, the scenario would be rejected as inconsistent. In a consistent scenario, the arrows for the maximum impact balance for the trend alternatives of a descriptor would always refer to the arrows of the included trend alternative in the scenario (Figure 4). Hence, a future scenario including a decrease in land use pressures, a global food crisis and a loss of importance of the CAP was regarded as not plausible by the software algorithm. Individual negative interactions do not necessarily lead to a rejection of the consistency of the scenario; the decisive factor in the end is the impact balance (Weimer-Jehle, 2021).

In the output of the software algorithm, all consistent scenarios were in text form and they were filtered in respect to the inclusion of the trend alternative F1 (improvement of biodiversity) as outlined in Table 1. The individual scenarios identified were finally aggregated according to their similarities into pathways that can lead to an improvement in biodiversity in agricultural landscapes, that is, the scenarios only differ in individual trend alternatives or several similar combinations are possible. The similarities were identified qualitatively within a group discussion by the authors.

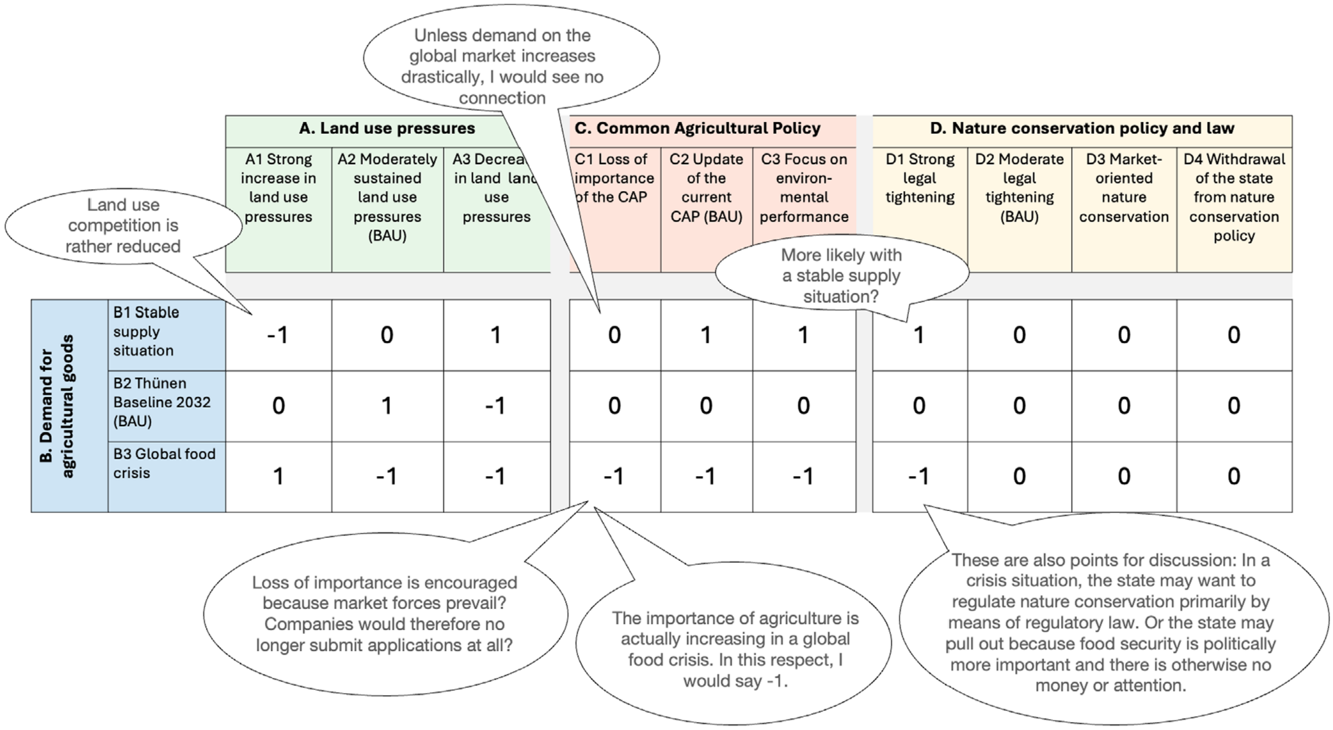

FIGURE 3 Schematic representation of the interaction assessment within the stakeholder workshops (example) with paraphrased arguments from participants in the bubbles.

3 | RESULTS

We found that the interactions between the respective descriptors or socio-economic drivers of biodiversity in agricultural landscapes are highly differentiated and can be regarded as complex. This complexity is also reflected in the fact that the three expert groups assessed some of the relationships differently. Figure 5 shows the range of relative impacts between the respective descriptors as a result of the three workshops. In this context, a zero means that no effect was seen between the potential developments of a descriptor in the row and the development of the descriptor in the corresponding column. For example, all expert groups concluded that there is no impact of land use pressure on demand for agricultural products or on social values. However, there are impacts in the opposite direction, that is, the demand for agricultural goods has an impact on land use pressure. Figure 5 also shows that some descriptors are more passive and others more active, that is, they either receive impacts from other socio-economic drivers or have impacts on them. For example, societal values are a rather active driver, as they strongly influence other descriptors, but their developments are rather independent of them. In contrast, the role of agriculture is a rather passive driver, as it is strongly influenced by land use pressure or the CAP, for example, but does not directly influence the other descriptors.

While none of the descriptors is dependent on the development of biodiversity according to our results, biodiversity is very actively affected by the other descriptors. However, compared to other descriptors, technological and economic shocks have a more indirect impact on biodiversity.

Based on the analysis of the interactions between the descriptors or socio-economic drivers, we identified four pathways leading to an improvement of biodiversity in German agricultural landscapes: 'innovation and stricter legislation', 'major change in protein production and CAP shift', 'major change in protein production and national legislation' and 'major social changes compensate for a lack of innovation in food production' (Figure 6).

These were based on the analysis of the three CIB matrices generated within the expert workshops, where a total of 19 consistent scenarios were identified with the software algorithm that included an enhancement in biodiversity in German agricultural landscapes (trend alternative F1 was present in the scenarios). The individual analyses of the three CIB matrices also revealed overlaps in terms of consistent scenarios. Independently of each other, two identical consistent scenarios were identified from the CIB matrices of each of the three groups. In addition, five of the 19 scenarios were identified by at least two groups when analysing the respective CIB matrix (Table 3). We thus selected seven core scenarios based on the assumption that these are particularly robust compared to the others, as they were derived from the assessment of at least two different groups of experts. This means that all other scenarios did not end up in respective pathways as we cannot regard them as being sufficiently robust.

These seven core scenarios were then aggregated into four major pathways leading to biodiversity improvement in agricultural landscapes in Germany in the following way. Scenarios 1–4 are very similar, as they differ only in descriptors E and H, although any combinations of E1, E2 with H1 and H2 are possible. The constellations

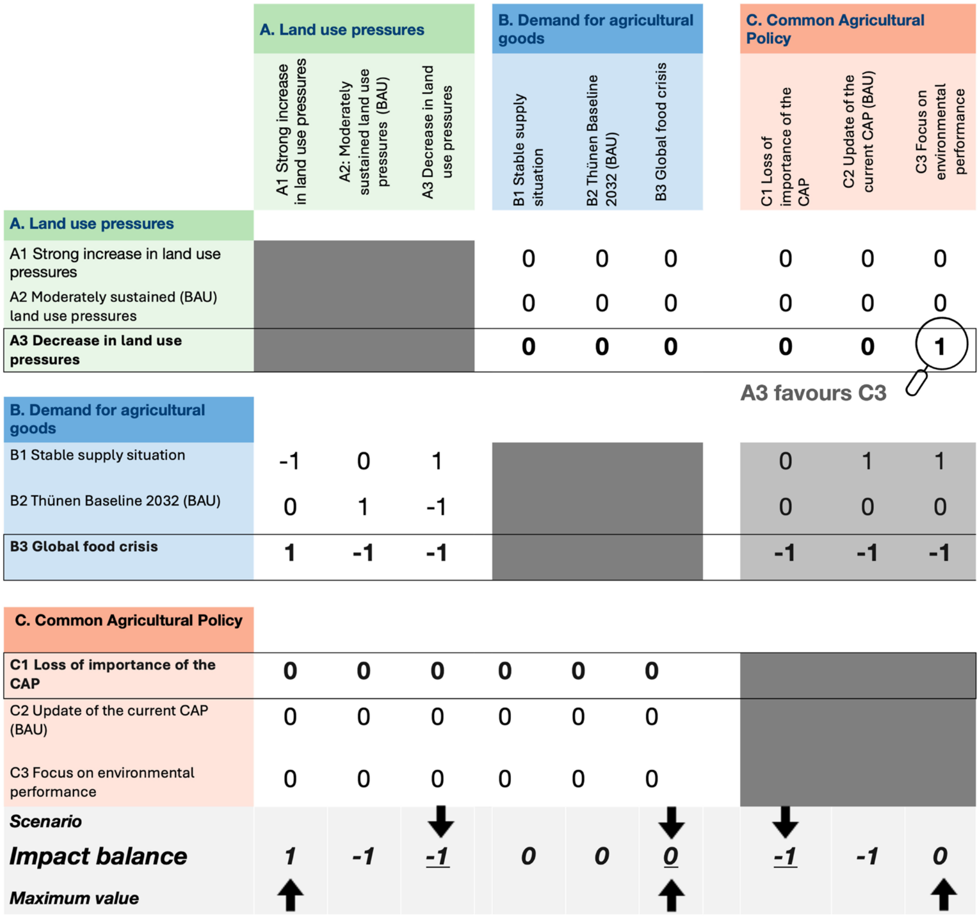

FIGURE 4 Schematic representation of an evaluation matrix of a cross-impact balance analysis with the reciprocal influence relationships in the evaluation levels favourable (+1), inhibiting (−1) and neutral or everything is plausible (0) and the impact balance for the combination of alternatives A3, B3 and C1. The impact balance is then calculated column by column across the selected rows A3, B3 and C1 (within black frames). In the first column, therefore, 1 + 0 = 1. In an ideal consistent scenario, the arrowheads would meet in each case. This means that the impact balance of the scenario reaches the maximum value for the respective descriptor (after Weimer-Jehle (2006)).

of scenarios 5 and 6, on the contrary, are only possible with H2, but not with H1, and represent independent pathways with different narratives, since there are different political needs for action. Scenario 7 can also be clearly distinguished because, unlike all the others, it contains no shock at descriptor H.

All of the four pathways (Figure 6) include the prerequisites of decreasing land use competition (A3), a stable supply situation on the global market (B1) and a stronger orientation of agriculture towards the provision of public goods (G1).

Pathway 1 ('Innovation and stricter legislation') depends on technological innovations in plant or protein production. In addition, there is a strong focus of the CAP on public goods as well as a stricter national nature conservation legislation. However, in contrast to pathway 4 a societal change towards sustainability and post-materialism must not necessarily take place, but would be also consistent with overall framework conditions.

Pathway 2 ('Major change in protein production and CAP shift') has strong similarities to pathway 1. However, in contrast to adjustments in national nature conservation legislation, there is a shift of the CAP orientation towards provision of public goods. Hence, any CAP policy premiums to farmers are therefore exclusively dependent on the provision of public services. The major prerequisite of this pathway are innovations in protein production, which means that about 25% of meat can be replaced by cellular protein.

Pathway 3 ('Major change in protein production and national legislation') is, in contrast to Pathway 2, not dependent on a CAP shift. Hence, the current CAP is continued with a slight shift towards environmental services (C2). However, in this path, there is a strong legal tightening in the nature conservation law, which includes, among other things, a ban on pesticides in protected areas (D1). In addition, there is a continuation of societal complexity without any dominant behavioural principles (E2). As with pathway 2, innovation in protein production is a fundamental requirement.

Pathway 4 ('Major social changes compensate for a lack of innovation in food production') is in contrast to all other pathways dependent on a major change of societal values towards sustainability and post-materialism as consensual orientation. There are no innovations in food production, i. e. protein or plant production and

	A. Land use pressure	B. Demand for agricultural goods	C. Common Agricultural Policy (CAP)	D. Nature conservation law and policy	E. Societal values	F. Biodiversity	G. Role of agriculture	H. Technological and economic shocks	Average active impact
A. Land use pressure	-	0	0.11-0.22	0.17-0.25	0	0.67-0.89	0.56-0.67	0	0.25-0.34
B. Demand for agricultural goods	0.33-0.78	-	0.44-0.56	0.08-0.41	0	0-0.89	0.22-0.78	0	0.15-0.48
C.Common Agricultural Policy (CAP)	0-0.22	0	-	0.08-0.25	0	0.78	0.67-0.88	0	0.22-0.30
D. Nature conservation law and policy	0.17-0.89	0	0-0.33	-	0	0.5-0.92	0.58-0.67	0	0.18-0.40
E. Societal values	0-1	0-0.08	0.22-0.67	0.75-0.91	-	0-0.67	0-0.78	0	0.14-0.59
F. Biodiversity	0	0	0	0	0	-	0	0	0
G. Role of agriculture	0	0	0-0.11	0	0	0.67-0.78	-	0	0.10-0.13
H. Technological and economic shocks	0.33-0.58	0.08-0.5	0.25-0.42	0.25-0.33	0-0.33	0-0.08	0.17-0.33	-	0.15-0.37
Innovations in plant production	0.67	0-0.67	0	0	0	0	0	-	0.10-0.20
Innovations in protein production	0.67	0-0.67	0	0-0.25	0	0-0.33	0-0.67	-	0.10-0.37
National economic slump	0-1	0	0.67-1	0.25-0.5	0-0.67	0-0.33	0.33	-	0.18-0.55
Global recession	0-0.33	0-0.67	0.33-0.67	0.25-0.5	0-0.67	0	0-0.33	-	0.08-0.45
Average impact on descriptor (passive)	0.25-0.5	0.01-0,08	0.15-0.33	0.15-0.31	0-0.04	0.37-0.72	0.31-0.58	0	

FIGURE 5 Mutual relative influence of a descriptor in the row on a descriptor in the column. A zero means that the experts saw no influence (neither +1 nor −1) between all trend alternatives of the row descriptor and the alternatives of the column descriptor. The range refers to the ratings of the three groups. Cells with no impact (0) are marked in white, cells with a slight to medium impact (maximum up to 0.5) are marked in light green and cells with a strong impact (>0.5) are marked in dark green. The average active impact of a descriptor or average passive impact on a descriptor is based on the average range for technological and economic shocks.

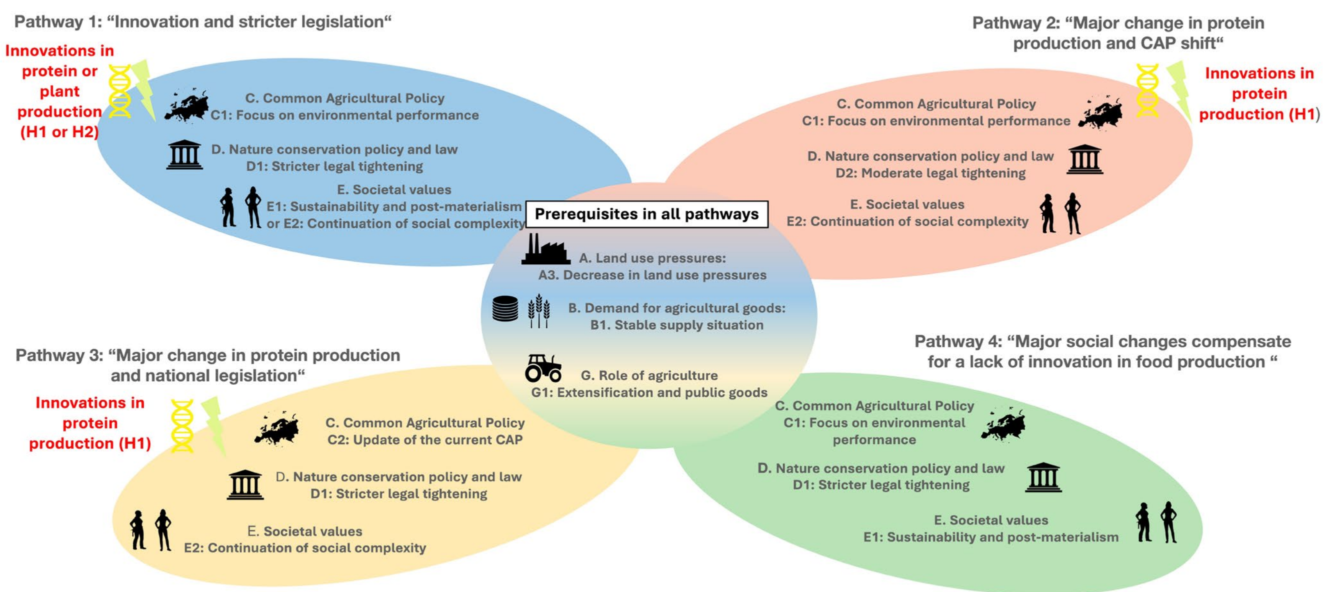

FIGURE 6 Schematic representation of future development pathways (with the target year 2030) based on the seven identified scenarios with biodiversity enhancement in the agricultural landscape in Germany
(source: own presentation).

major changes in terms of stricter nature conservation legislation (D1) and orientation of the CAP towards public goods (C1). Societal change was considered by all expert groups to favour a shift towards stricter nature conservation legislation and a focus of the CAP on public goods. Hence, societal values can be regarded as one key component of the respective pathway.

TABLE 3 Overview of the consistent scenarios for the improvement of biodiversity in German agricultural landscapes that have been derived from the expert-based assessments within the three groups and the aggregation of overlapping scenarios between the groups to four pathways ('X' means that a scenario includes the respective trend alternative) (source: own presentation).

	Scenarios from the mixed (M), nature conservation (N) and agricultural (A) group																		
	M, A, N		M, N		A, N	M, A		N	N	N	N	N	A	A	A	A	A	M	M
Descriptor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
A. Land use pressures																			
A1. Strong increase in land use pressures																X			
A2. Moderately sustained land use pressures (BAU)																			
A3. Decrease in land use pressures	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
B. Demand for agricultural goods																			
B1. Stable supply situation	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X
B2. Thünen Baseline 2032 (BAU)									X	X									
B3. Global food crisis																			
C. Common Agricultural Policy																			
C1. Loss of importance of the CAP									X	X	X	X							
C2. Update of the current CAP (BAU)						X									X				
C3. Focus on environmental performance	X	X	X	X	X		X	X					X	X		X	X	X	X
D. Nature conservation policy and law																			
D1. Stricter legal tightening	X	X	X	X		X	X									X		X	X
D2. Moderate legal tightening (BAU)					X			X					X	X	X		X		
D3. Market-oriented nature conservation									X	X	X	X							
D4. Withdrawal of the state from nature conservation policy																			
E. Societal values																			
E1. Sustainability and post-materialism	X	X					X				X		X				X		
E2. Continuation of social complexity (BAU)			X	X	X	X		X	X	X		X		X	X				
E3. Dominance of materialism																X		X	X
G. Role of agriculture																			
G1. Extensification and public goods	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
G2. Business-as-usual (BAU)																			
G3. Intensification of agriculture																			

(Continues)

TABLE 3 (Continued)

	Scenarios from the mixed (M), nature conservation (N) and agricultural (A) group																		
	M, A, N		M, N		A, N	M, A		N	N	N	N	N	A	A	A	A	A	M	M
Descriptor	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
H. Technological and economic shocks																			
H1. Innovations in plant production	X		X					X	X				X	X				X	
H2. Innovations in protein production		X		X	X	X				X					X	X			X
H3. National economic slump											X	X							
H4. Global recession																			
No shock (BAU)							X										X		
Pathway	1	1	1	1	2	3	4	–	–	–	–	–	–	–	–	–	–	–	–

We also found that some of the trend alternatives (that were not shown as pathways in this analysis) appear only in line with a higher decline of biodiversity (F3) across all scenarios based on the assessments from the three groups. This refers to a global food crisis (B3), the government withdrawal from nature conservation policy (D4) and the intensification of agricultural production (G3). Moreover, economic shocks (H3 and H4) were found to occur mainly in line with a decline of biodiversity (F3). However, from the assessment of the nature conservation group, two scenarios were also identified with an enhancement of biodiversity (F3). The main argument here was that economic shocks such as the loss of competitiveness of German industry might hinder the intensification of agriculture (G3) and favour a reduction in land use pressures (A3). In contrast to the other two groups, no inhibiting relationship was seen here between the economic shocks (H3 and H4) and the orientation of the CAP towards public goods (C3) or a legal tightening of national nature conservation law (D1). In general, the impacts of the two economic shocks on other trend alternatives were rated quite equally within one group.

4 | DISCUSSION

4.1 | Discussion of the results

We applied the CIB analysis to the agri-food system in order to understand how different socio-economic drivers of biodiversity in German agricultural landscapes interact (i) and to derive plausible pathways that will lead to enhanced biodiversity (ii). Finally, we discuss guiding principles for policy-making (iii).

There are more or less pronounced relationships of influence between the socio-economic drivers considered (i). While some drivers, such as societal values, are rather independent and have strong active impacts, others, such as the role of agriculture, are more passive in nature and are comparatively strongly influenced by other drivers. In addition, global demand for agricultural goods is rather independent from the development of the other socio-economic drivers; however, it has a comparatively high impact on the CAP, the role of agriculture or land use pressure. National trends in agricultural land use are therefore strongly linked to global trends and thus to shifts in the global market for agricultural goods, which is in line with the literature (Klebl et al., 2024; Mupepele et al., 2021). In the context of a global food crisis, for example, due to failed harvests as a result of climate change, more extensive agriculture seems hardly conceivable. In such a situation, price signals on the world market would, according to experts, lead to strong export pressures that are unlikely to be absorbed by policy measures in the CAP (Timpanaro et al., 2023). Such intensive management could also conflict with soil conservation, particularly the retention of organic matter content, which is important for long-term productivity and biodiversity (Eisenhauer et al., 2024; Kopittke et al., 2019; Tsiafouli et al., 2015). We also found that institutional drivers such as the CAP or environmental legislation play a pivotal role in the development of paradigms for agricultural production, for instance, towards the provision of public goods by means of a stronger legal tightening or focus of the CAP on environmental performance. This is in line with Van Vliet et al. (2015) who conclude that agricultural land use change is influenced by a wide range of underlying factors such as economic, socio-cultural and, in particular, institutional factors such as subsidies.

Societal values especially interact with the development of nature conservation law and policy. All expert groups concluded that a transition of societal values towards enhanced sustainability and post-materialism will favour a legal tightening of regulatory law such as stricter regulations on the use of pesticides or synthetic fertilizers. Chan et al. (2020) also stress the importance of societal values in achieving legal changes for nature conservation.

In summary, our analysis showed complex interactions and impacts between drivers and their respective future trend alternatives, which is in line with the literature (Díaz & Malhi, 2022). To enhance biodiversity in agricultural landscapes, it is not enough for individual drivers to move in a favourable direction, for example, decreasing land use pressures, but it requires the interplay of multiple drivers (Jaureguiberry et al., 2022; Mupepele et al., 2021).

All four pathways supporting biodiversity depended on decreasing land use pressures, a stable supply on the global market as well as on a stronger orientation of agriculture towards the provision of public goods (Grethe et al., 2018). Habitat loss due to urbanization is also acknowledged by other studies as a major threat to biodiversity conservation in the future (McDonald et al., 2019; Simkin et al., 2022). Busse et al. (2021) stressed that economic pressures induced by global trade of agricultural goods pose a risk to biodiversity protection, which is in line with our findings. Similar to our results, Pröbstl et al. (2023) found the need for increased valuation of multifunctional agriculture in terms of public goods. Each pathway contains at least the tightening of the national nature conservation law or an orientation of the CAP towards environmental performance (Pe'er et al., 2022), which demonstrates the close political interlinkages. It also became clear that although the CAP is sometimes criticized regarding its performance in nature conservation (Pe'er et al., 2019; Pröbstl et al., 2023), it is highly relevant for biodiversity in agricultural landscapes in all pathways.

Three out of the four pathways involved innovations in plant or protein production. Without these innovations, an improvement in biodiversity seems less likely. This is in line with Ewert et al. (2023), stating that innovations in plant production such as NBTs can foster the transformation towards more sustainable agri-food systems. Only pathway 4 did not involve such innovations but depends, among other things, on a major change in societal values towards sustainability and biodiversity-oriented consumer choices. Such a change in societal values with corresponding changes in diet can contribute, for example, to reducing pressure on land use and will probably favour political decisions to focus CAP payments on environmental objectives or to tighten national nature conservation legislation, depending on the experts' assessments. The importance of dietary changes, including reduced meat consumption and strong legislation for nature conservation and sustainable agricultural production, was also identified in Visconti et al. (2016) and Parlasca and Qaim (2022) as important for global biodiversity improvement. Meat consumption and land use associated with livestock farming for feed production are considered a key factor influencing biodiversity in agricultural landscapes (Crenna et al., 2019).

Although Chan et al. (2020) also highlight innovations and social values as leverage points for a transformation to sustainability in general, they did not analyse their interactions and the results were derived from a global perspective and thus are not specific to different national framework conditions.

Using the example of Germany, the pathway concept provides us with a strategic perspective, showing different options for achieving a desired goal with respect to the relationship between human activities and biodiversity. The pathways revealed strong interconnections between the social, economic and ecological dimensions and encourage us to re-think human-nature relations in agri-food systems with a focus on biodiversity, also beyond the German case. The concept's holistic perspective enables a constructive dialogue between actors from different sectors and disciplines, for example, the public, farmers and policymakers, on controversial perspectives regarding biodiversity conservation (Beland Lindahl et al., 2016). This is because the pathways clearly show the options and related trade-offs for achieving a specific goal, such as preserving biodiversity. They emphasize the responsibility of society as a whole, rather than focusing on individual actors such as farmers, who frequently feel blamed by society for the decline in biodiversity (Busse et al., 2021).

4.2 | General guiding principles for policy-making to enhance biodiversity

It is not possible to derive concrete recommendations for specific policy instruments from the results of our analysis, given the applied CIB methodology and the required level of abstraction in the explanation of the descriptors. Nevertheless, the following guiding principles (iii) can be derived that policymakers at different spatial scales, for example, actors in regional planning or members of the federal parliament, should take into account if they want to enhance biodiversity in agricultural landscapes in Germany.

4.2.1 | Reduce land use pressures

Reducing land use competition remains a major lever for addressing biodiversity loss in the future (IPBES, 2019). The seven core scenarios and 14 of the total of 15 scenarios are based on the assumption that land pressure will decrease with the achievement of the target set in the German Sustainable Development Strategy of land consumption of less than 30 ha by 2030 (Die Bundesregierung, 2021). However, there could also be conflicting objectives at this point, as large-scale rewetting of peatlands would represent a significant use of agricultural land in terms of spatial dimensions. Innovative and multifunctional land use systems are therefore particularly important for peatland protection. Potential synergies between climate protection and biodiversity should be exploited here (Wüstemann et al., 2017), but also in the field of renewable energies such as agrivoltaics instead of ground-mounted systems on agricultural land (Feuerbacher et al., 2022; Sponagel, Weik, et al., 2024).

4.2.2 | Create value for biodiversity within society

Creating value for biodiversity within society can have substantial effects on the development of biodiversity in the agricultural landscape. This refers to the appreciation of environmental services provided by farms and related consumption behavior. Education and information about the value of biodiversity on the consumer side play a major role in this context (Boix-Fayos & De Vente, 2023). Although biodiversity has gained attention in response to the publication of the study by Hallmann et al. (2017) and medial dissemination (Felgentreff et al., 2023), it still remains challenging to impact consumer choices by sustainability labels, for instance (Gorton et al., 2021; Majer et al., 2022). In addition, financing biodiversity-friendly farming practices solely via the market and respective price surcharges is still rather unlikely in Germany (Sponagel, Witte, & Bahrs, 2024).

4.2.3 | Adapt agricultural policy and nature conservation legislation

According to the results, the CAP should be strongly focused on improving the ecosystem functions of agri-food systems in the future, which can also favour the necessary transformation of agriculture with regard to the stronger promotion of biodiversity and ecosystem services (other than only food provision) and the provision of public goods (see also Mupepele et al. (2021)). Based on the results, a stronger legal tightening of nature conservation and compliance/control for agri-environmental funding schemes can also be recommended. This includes, for example, the reduction of synthetic chemical pesticides in protected areas and greater avoidance of structural interventions in the ecosystem. Stricter legislation on the use of pesticides should be accompanied by a supportive legal framework, as this is important for the acceptance of the measures in agriculture and ultimately also for their ecological effectiveness (Busse et al., 2021). Also, the coherence between the CAP and nature conservation legislation should be improved, for instance funding of the Natura 2000 network by means of the CAP (Hodge et al., 2015). In general, also a policy mix of legislation and funding schemes can be suitable to achieve specific environmental objectives. In addition, considerable need for further research exists on the effects on large-scale pesticide-free crop production in particular because, currently, yields can only be estimated with a high degree of uncertainty for many crops (Mack et al., 2023).

4.2.4 | Foster innovations in agri-food systems

Technological innovations in crop and protein production considerably increased the scope for action with regard to a transformation towards improving biodiversity in agricultural landscapes. Hence, more emphasis should be placed on putting innovations in plant and protein production into practice. This includes the consideration of digitalization and new breeding technologies in agroecological transformation as they can potentially improve crop yields and/or reduce the use of pesticides, for instance (Ewert et al., 2023; Qaim, 2020), but also the promotion of hybrid approaches that draw on the combination of human and artificial intelligence (Berger et al., 2024). However, at this point there are numerous challenges and trade-off decisions to be made between societal interests and the consequences for rural areas and questions such as how cellular meat and traditional pasture farming can coexist to preserve extensive grassland (Moritz et al., 2022).

4.2.5 | Enhance the resilience of global agri-food systems

In addition to policy instruments, such as the nature conservation law, the global food situation also plays a decisive role with regard to the development of biodiversity in Germany. In this respect, all seven core scenarios and 14 of the 15 scenarios overall assume a stable situation on the global market with consequently moderate prices for agricultural goods and rather low export pressure from the perspective of agriculture in Germany. None of the consistent scenarios with an improvement in biodiversity contain the trend alternative of a global food crisis and consequently increasing export pressure. Similarly, none of the scenarios are consistent with an intensification of agricultural production and an increase in input. Hence, effort should be made to foster the development of resilient agri-food systems, for instance by fostering research in the context of climate change mitigation and adaptation (Nationale Akademie der Wissenschaften Leopoldina et al., 2020).

4.3 | Critical reflection on the applied methodology

Qualitative methods such as the CIB approach can broaden our understanding of systems and help to identify hypotheses or existing research gaps, and therefore provide a valuable foundation for further quantitative analyses. In particular, analysing the impact of abrupt shocks to a system can be challenging with quantitative models as they are often not designed for such purposes (Elsawah et al., 2020).

In contrast to other approaches that rely on formative scenario analysis with similar expert-based consistency matrices between different future states of system variables (e. g. Walz et al. (2014)), the CIB methodology allowed us to analyse the two-way interactions and impacts between multiple drivers of biodiversity in the German agri-food system. In this way, the developed pathways are based on a comparatively holistic perspective and can thus contribute to a systemic understanding of the trade-offs and synergies between multiple drivers, which would not have been possible if only individual relationships had been considered. In our experience, the major benefit of the method is that it provides a formalized process for experts from different backgrounds to exchange arguments, leading to better mutual understanding and ultimately consensus in a time-efficient manner. Due to the experts' tight schedules, time efficiency was also relevant for selecting the method. In this context, we also received positive feedback from the invited experts that the discussions were perceived as stimulating because of the exchange among disciplines and stakeholder groups. Hence, the methodological approach is able to bring researchers or stakeholders to re-think their perceptions and concepts. The interactive exchange format also helped to clarify some of the initial critical feedback from individual experts regarding their understanding of the method and the descriptors.

Although the invitation to the workshops was widely distributed, a selection effect cannot be ruled out and other experts could arrive at different assessments (Kaiser, 2021). A large share of experts had a scientific perspective. We have to acknowledge that the perspective of small-scale farming, including approaches such as community-supported agriculture or solidarity-based agriculture (Parot et al., 2024) might have been rather underrepresented by the selected experts. In addition, the perspective of social science was underrepresented in the group of environmental experts. However, as the results from the three separate groups differed only slightly, we are confident that our results are sufficiently robust. Nevertheless, it might be useful to include an even broader range of non-scientific stakeholders in subsequent studies, for example, from the food industry, policymakers or administration and farmers.

The assessment of the influencing relationships was not differentiated in terms of strength, as this was perceived as too complex. If more data and knowledge on the mutual relationship between individual descriptors become available in the future, the assessment carried out here could be further differentiated and refined, for instance by coupling quantitative models with the CIB (Kosow et al., 2022). In addition, the definition of the descriptors and trend alternatives must be critically reflected upon. Focusing on socio-economic drivers, climate change was not considered. Climate change in particular is a significant influencing factor as interactions between land use intensity and biodiversity impacts have been demonstrated (Outhwaite et al., 2022; Raven & Wagner, 2021). However, the target year for the analysis was 2030, and the effects of climate change on biodiversity and agriculture are expected to increase over time and have a much greater impact in the more distant future (Hasegawa et al., 2022; Newbold, 2018). Increasing the number of descriptors and/or trend alternatives could also reduce the practicability of the method, as the increasing complexity may make it more difficult for experts to grasp the context and may therefore have reduced the willingness of experts to participate in this activity.

Workshop discussions also revealed a need for future research, for example into the aspect of market-orientated nature conservation. This was only included in the scenarios of the nature conservation group (Table 3). The relationship between market-oriented nature conservation and biodiversity was rated as zero for F1 to F3 in the agricultural group, which indicated that the experts were probably unsure about the causal relationships. One practical example for market-oriented nature conservation is the 'Agriculture for Biodiversity' product label, however, the area effect is currently still limited and a majority willingness to buy biodiversity-friendly products has so far been identified for a few organic products only (Runge, 2020). Sponagel, Witte, and Bahrs (2024) showed limited potential for price premiums for biodiversity-friendly labelled food products, up to 10%, according to a survey of food industry companies. In addition, possible leakage effects, that is, negative impacts on biodiversity in other parts of the world due to the extensification of agriculture and a focus on public goods were not considered and should be analysed in following studies (Wesseler, 2022).

5 | CONCLUSIONS

In this paper we applied the CIB methodology to derive four different future pathways leading to enhanced biodiversity in German agricultural landscapes. Although some aspects of the pathways' content, such as the need to reduce land use pressure, are not entirely new, the added value of our analysis primarily lies in the application of the conceptual framework to a specific case study for identifying concrete pathways. The comparatively holistic and systematic approach with a strong focus on the interactions between multiple socio-economic drivers of biodiversity in agricultural landscapes is a unique feature of the study.

Societal values are a strong leverage point to improve biodiversity and need thus to be given high priority in public perception for this purpose. Interaction between society, policy and science is needed, as demonstrated by the potentially high relevance of innovations. The innovations need to go hand in hand with the acceptance of society. Once more, the results re-emphasize the importance of a strong legal framework in environmental legislation and the relevance of the CAP to improve biodiversity in agricultural landscapes. A key message to policymakers is that there is not just one pathway, indicating that the goal of enhancing biodiversity in agricultural landscapes can be achieved through different mechanisms. This seems important in the case of the CAP, for example. If a stronger focus on environmental goods cannot be achieved at the European level, then a main entry point for improving biodiversity would be through nature conservation legislation at the national level.

In future research, our framework can serve as a template that aims at developing pathways for enhancing biodiversity in other countries within the European Union. This would also allow testing for differences and similarities in pathways across countries. The pathways presented here can further form the basis for quantitative economic modelling of the agricultural sector, particularly regarding the impact of innovations in protein and plant production, in order to better understand and classify them in the future.

AUTHOR CONTRIBUTIONS

Christian Sponagel, Amibeth Thompson and Sebastian Lakner conceived the ideas and designed methodology; Christian Sponagel and Amibeth Thompson collected the data; Christian Sponagel analysed the data; Christian Sponagel, Amibeth Thompson and Sebastian Lakner led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

ACKNOWLEDGEMENTS

We would like to thank the participants of our workshops for their contribution to this paper. The project on which this report is based was funded by the German Federal Ministry of Education and Research within the Research Initiative for the Conservation of Biodiversity (FEdA) under the funding code 16LC2001B and 16LC2001F. Publishing fees were supported by the Funding Programme Open Access Publishing of the University of Hohenheim. The responsibility for the content of this publication lies with the authors. Open Access funding enabled and organized by Projekt DEAL.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data generated within this study is available within the manuscript or its Supporting Information.

ORCID

Christian Sponagel https://orcid.org/0000-0003-4637-4916
Amibeth Thompson https://orcid.org/0000-0002-9224-412X
Anne-Christine Mupepele https://orcid.org/0000-0002-5671-0963
Claudia Bieling https://orcid.org/0000-0001-5001-4150
Alexandra-Maria Klein https://orcid.org/0000-0003-2139-8575
Josef Settele https://orcid.org/0000-0002-8624-4983
Robert Finger https://orcid.org/0000-0002-0634-5742
Robert Huber https://orcid.org/0000-0003-4545-456X
Christian Albert https://orcid.org/0000-0002-2591-4779
Juliane Filser https://orcid.org/0000-0003-1535-6168
Florian Jansen https://orcid.org/0000-0002-0331-5185
Vera Schreiner https://orcid.org/0000-0002-8744-0804
Sebastian Lakner https://orcid.org/0000-0002-5122-8924

REFERENCES

Abson, D. J., Fischer, J., Leventon, J., Newig, J., Schomerus, T., Vilsmaier, U., Von Wehrden, H., Abernethy, P., Ives, C. D., Jager, N. W., & Lang, D. J. (2017). Leverage points for sustainability transformation. *Ambio*, *46*, 30–39. https://doi.org/10.1007/s13280-016-0800-y

Aguiar, A. P. D., Collste, D., Harmáčková, Z. V., Pereira, L., Selomane, O., Galafassi, D., Van Vuuren, D., & Van Der Leeuw, S. (2020). Co-designing global target-seeking scenarios: A cross-scale participatory process for capturing multiple perspectives on pathways to sustainability. *Global Environmental Change*, *65*, 102198. https://doi.org/10.1016/j.gloenvcha.2020.102198

Assandri, G., Bogliani, G., Pedrini, P., & Brambilla, M. (2018). Beautiful agricultural landscapes promote cultural ecosystem services and biodiversity conservation. *Agriculture, Ecosystems and Environment*, *256*, 200–210. https://doi.org/10.1016/j.agee.2018.01.012

Beaumelle, L., Tison, L., Eisenhauer, N., Hines, J., Malladi, S., Pelosi, C., Thouvenot, L., & Phillips, H. R. P. (2023). Pesticide effects on soil fauna communities—A meta-analysis. *Journal of Applied Ecology*, *60*, 1239–1253. https://doi.org/10.1111/1365-2664.14437

Beland Lindahl, K., Baker, S., Rist, L., & Zachrisson, A. (2016). Theorising pathways to sustainability. *The International Journal of Sustainable Development World Ecology*, *23*, 399–411. https://doi.org/10.1080/13504509.2015.1128492

Berger, T., Gimpel, H., Stein, A., Troost, C., Asseng, S., Bichler, M., Bieling, C., Birner, R., Grass, I., Kollmann, J., Leonhardt, S. D., Schurr, F. M., & Weisser, W. (2024). Hybrid intelligence for reconciling biodiversity and productivity in agriculture. *Nature Food*, *5*, 270–272. https://doi.org/10.1038/s43016-024-00963-6

BfN. (2017). *PDF: NaBiV Heft 156: Rote Liste der gefährdeten Biotoptypen Deutschlands. Bundesamt für Naturschutz* (1st ed.). Landwirtschaftsverlag GmbH.

BfN. (2023). *Anteil der Landwirtschaftsflächen mit hohem Naturwert an der Agrarlandschaftsfläche Deutschlands in den Jahren 2009 bis 2022 in Prozent*. Gesamtindikator und Teilindikatoren.

Bieling, C., Eser, U., & Plieninger, T. (2020). Towards a better understanding of values in sustainability transformations: Ethical perspectives on landscape stewardship. *Ecosystems and People*, *16*, 188–196. https://doi.org/10.1080/26395916.2020.1786165

BMEL. (2022). *Statistisches Jahrbuch über Ernährung, Landwirtschaft und Forsten der Bundesrepublik Deutschland*. Bundesministerium für Ernährung und Landwirtschaft (BMEL) [WWW document]. https://www.bmel-statistik.de/fileadmin/SITE_MASTER/content/Jahrbuch/Agrarstatistisches-Jahrbuch-2022.pdf

BMU. (2007). *Nationale Strategie zur biologischen Vielfalt vom Bundeskabinett am 7. November 2007 beschlossen*. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU) [WWW document]. https://www.cbd.int/doc/world/de/de-nbsap-01-de.pdf

Boix-Fayos, C., & De Vente, J. (2023). Challenges and potential pathways towards sustainable agriculture within the European Green Deal. *Agricultural Systems*, *207*, 103634. https://doi.org/10.1016/j.agsy.2023.103634

Brühl, C. A., Engelhard, N., Bakanov, N., Wolfram, J., Hertoge, K., & Zaller, J. G. (2024). Widespread contamination of soils and vegetation with current use pesticide residues along altitudinal gradients in a European alpine valley. *Communications Earth & Environment*, *5*, 72. https://doi.org/10.1038/s43247-024-01220-1

Bürgi, M., Hersperger, A. M., & Schneeberger, N. (2005). Driving forces of landscape change - current and new directions. *Landscape Ecology*, *19*, 857–868. https://doi.org/10.1007/s10980-005-0245-3

Busse, M., Zoll, F., Siebert, R., Bartels, A., Bokelmann, A., & Scharschmidt, P. (2021). How farmers think about insects: Perceptions of biodiversity, biodiversity loss and attitudes towards insect-friendly farming practices. *Biodiversity and Conservation*, *30*, 3045–3066. https://doi.org/10.1007/s10531-021-02235-2

Campbell, B. M., Beare, D. J., Bennett, E. M., Hall-Spencer, J. M., Ingram, J. S. I., Jaramillo, F., Ortiz, R., Ramankutty, N., Sayer, J. A., & Shindell, D. (2017). Agriculture production as a major driver of the Earth system exceeding planetary boundaries. *Ecology and Society*, *22*, art8. https://doi.org/10.5751/ES-09595-220408

CBD. (1992). *Convention on biological diversity*. CBD.

Chan, K. M. A., Boyd, D. R., Gould, R. K., Jetzkowitz, J., Liu, J., Muraca, B., Naidoo, R., Olmsted, P., Satterfield, T., Selomane, O., Singh, G. G., Sumaila, R., Ngo, H. T., Boedhihartono, A. K., Agard, J., De Aguiar, A. P. D., Armenteras, D., Balint, L., Barrington-Leigh, C., … Brondízio, E. S. (2020). Levers and leverage points for pathways to sustainability. *People and Nature*, *2*, 693–717. https://doi.org/10.1002/pan3.10124

Coupe, R. H., Barlow, J. R. B., & Capel, P. D. (2012). Complexity of human and ecosystem interactions in an agricultural landscape. *Environment and Development*, *4*, 88–104. https://doi.org/10.1016/j.envdev.2012.09.009

Crenna, E., Sinkko, T., & Sala, S. (2019). Biodiversity impacts due to food consumption in Europe. *Journal of Cleaner Production*, *227*, 378–391. https://doi.org/10.1016/j.jclepro.2019.04.054

Di Pirro, E., Sallustio, L., Capotorti, G., Marchetti, M., & Lasserre, B. (2021). A scenario-based approach to tackle trade-offs between biodiversity conservation and land use pressure in Central Italy. *Ecological Modelling*, *448*, 109533. https://doi.org/10.1016/j.ecolmodel.2021.109533

Díaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., Larigauderie, A., Adhikari, J. R., Arico, S., Báldi, A., Bartuska, A., Baste, I. A., Bilgin, A., Brondizio, E., Chan, K. M., Figueroa, V. E., Duraiappah, A., Fischer, M., Hill, R., … Zlatanova, D. (2015). The IPBES conceptual framework—Connecting nature and people.

Current Opinion in Environment Sustainability, *14*, 1–16. https://doi.org/10.1016/j.cosust.2014.11.002

Díaz, S., Demissew, S., Joly, C., Lonsdale, W. M., & Larigauderie, A. (2015). A Rosetta stone for nature's benefits to people. *PLoS Biology*, *13*, e1002040. https://doi.org/10.1371/journal.pbio.1002040

Díaz, S., & Malhi, Y. (2022). Biodiversity: Concepts, patterns, trends, and perspectives. *Annual Review of Environment and Resources*, *47*, 31–63. https://doi.org/10.1146/annurev-environ-120120-054300

Die Bundesregierung. (2021). *Deutsche Nachhaltigkeitsstrategie. Weiterentwicklung 2021*. Die Bundesregierung.

Eisenhauer, N., Ristok, C., Guerra, C. A., Tebbe, C. C., Xylander, W., Babin, D., Bartkowski, B., Burkhard, B., Filser, J., Glante, F., Hohberg, K., Kleemann, J., Kolb, S., Lachmann, C., Lehmitz, R., Rillig, M., Römbke, J., Rueß, L., Scheu, S., … Wellbrock, N. (2024). Bodenbiodiversität. In C. Wirth, H. Bruelheide, N. Farwig, J. Marx, & J. Settele (Eds.), *Faktencheck Artenvielfalt. Bestandsaufnehme und Perspektiven für den Erhalt der biologischen Vielfalt in Deutschland* (pp. 917–1048). Oekom Verlag.

Elsawah, S., Hamilton, S. H., Jakeman, A. J., Rothman, D., Schweizer, V., Trutnevyte, E., Carlsen, H., Drakes, C., Frame, B., Fu, B., Guivarch, C., Haasnoot, M., Kemp-Benedict, E., Kok, K., Kosow, H., Ryan, M., & Van Delden, H. (2020). Scenario processes for socio-environmental systems analysis of futures: A review of recent efforts and a salient research agenda for supporting decision making. *Science of the Total Environment*, *729*, 138393. https://doi.org/10.1016/j.scitotenv.2020.138393

Eurostat. (2024a). *Crop production in national humidity* [WWW document]. https://ec.europa.eu/eurostat/databrowser/view/apro_cpnh1__custom_11334882/default/table?lang=en

Eurostat. (2024b). *Economic accounts for agriculture—Values at current prices* [WWW document]. https://ec.europa.eu/eurostat/databrowser/view/aact_eaa01/default/table?lang=en

Ewert, F., Baatz, R., & Finger, R. (2023). Agroecology for a sustainable agriculture and food system: From local solutions to large-scale adoption. *Annual Review of Resource Economics*, *15*, 351–381. https://doi.org/10.1146/annurev-resource-102422-090105

FAO. (2021). *In brief the state of food and agriculture 2021*. FAO. https://doi.org/10.4060/cb7351en

Felgentreff, E. S., Buchholz, S., & Straka, T. M. (2023). From science to society to practice? Public reactions to the insect crisis in Germany. *People and Nature*, *5*, 660–667. https://doi.org/10.1002/pan3.10434

Feuerbacher, A., Herrmann, T., Neuenfeldt, S., Laub, M., & Gocht, A. (2022). Estimating the economics and adoption potential of agrivoltaics in Germany using a farm-level bottom-up approach. *Renewable and Sustainable Energy Reviews*, *168*, 112784. https://doi.org/10.1016/j.rser.2022.112784

Fischer, J., & Riechers, M. (2019). A leverage points perspective on sustainability. *People and Nature*, *1*, 115–120. https://doi.org/10.1002/pan3.13

Flörke, M., Schneider, C., & McDonald, R. I. (2018). Water competition between cities and agriculture driven by climate change and urban growth. *Nature Sustainability*, *1*, 51–58. https://doi.org/10.1038/s41893-017-0006-8

Galler, C., Von Haaren, C., & Albert, C. (2015). Optimizing environmental measures for landscape multifunctionality: Effectiveness, efficiency and recommendations for agri-environmental programs. *Journal of Environmental Management*, *151*, 243–257. https://doi.org/10.1016/j.jenvman.2014.12.011

Gorton, M., Tocco, B., Yeh, C.-H., & Hartmann, M. (2021). What determines consumers' use of eco-labels? Taking a close look at label trust. *Ecological Economics*, *189*, 107173. https://doi.org/10.1016/j.ecolecon.2021.107173

Grethe, H., Arens-Azevedo, U., Balmann, A., Biesalski, H. K., Birner, R., Bokelmann, W., Christen, O., Gauly, M., Knierim, U., Latacz-Lohmann, U., Martínez, J., Nieberg, H., Offermann, F., Pischetsrieder, M., Qaim, M., Renner, B., Schmid, J. C., Spiller, A., Taube, F., … Weingarten, P. (2018). *Für eine gemeinwohlorientierte Gemeinsame Agrarpolitik der EU nach 2020: Grundsatzfragen und Empfehlungen*. Stellungnahme. Berichte Über Landwirtsch. - Z. Für Agrarpolit. Landwirtsch. Sonderheft 225, Juni 2018. https://doi.org/10.12767/BUEL.V0I225.208

Hallmann, C. A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., Stenmans, W., Müller, A., Sumser, H., Hörren, T., Goulson, D., & de Kroon, H. (2017). More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PLoS One*, *12*, e0185809. https://doi.org/10.1371/journal.pone.0185809

Hallmann, C. A., Ssymank, A., Sorg, M., de Kroon, H., & Jongejans, E. (2021). Insect biomass decline scaled to species diversity: General patterns derived from a hoverfly community. *Proceedings of the National Academy of Sciences of the United States of America*, *118*, e2002554117. https://doi.org/10.1073/pnas.2002554117

Hamilton, H., Henry, R., Rounsevell, M., Moran, D., Cossar, F., Allen, K., Boden, L., & Alexander, P. (2020). Exploring global food system shocks, scenarios and outcomes. *Futures*, *123*, 102601. https://doi.org/10.1016/j.futures.2020.102601

Hasegawa, T., Wakatsuki, H., Ju, H., Vyas, S., Nelson, G. C., Farrell, A., Deryng, D., Meza, F., & Makowski, D. (2022). A global dataset for the projected impacts of climate change on four major crops. *Scientific Data*, *9*, 58. https://doi.org/10.1038/s41597-022-01150-7

Haß, M., Deblitz, C., Freund, F., Kreins, P., Laquai, V., Offermann, F., Pelikan, J., Sturm, V., Wegmann, J., de Witte, T., Wüstemann, F., & Zinnbauer, M. (2022). *Thünen-Baseline 2022–2032: Agrarökonomische Projektionen für Deutschland*. Johann Heinrich von Thünen-Institut.

Hering, D., Schürings, C., Wenskus, F., Blackstock, K., Borja, A., Birk, S., Bullock, C., Carvalho, L., Dagher-Kharrat, M. B., Lakner, S., Lović, N., McGuinness, S., Nabuurs, G.-J., Sánchez-Arcilla, A., Settele, J., & Pe'er, G. (2023). Securing success for the nature restoration law. *Science*, *382*, 1248–1250. https://doi.org/10.1126/science.adk1658

Hermoso, V., Carvalho, S. B., Giakoumi, S., Goldsborough, D., Katsanevakis, S., Leontiou, S., Markantonatou, V., Rumes, B., Vogiatzakis, I. N., & Yates, K. L. (2022). The EU biodiversity strategy for 2030: Opportunities and challenges on the path towards biodiversity recovery. *Environmental Science & Policy*, *127*, 263–271. https://doi.org/10.1016/j.envsci.2021.10.028

Hodge, I., Hauck, J., & Bonn, A. (2015). The alignment of agricultural and nature conservation policies in the European Union. *Conservation Biology*, *29*, 996–1005. https://doi.org/10.1111/cobi.12531

IPBES. (2019). *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. IPBES. https://doi.org/10.5281/zenodo.3831673

Jaureguiberry, P., Titeux, N., Wiemers, M., Bowler, D. E., Coscieme, L., Golden, A. S., Guerra, C. A., Jacob, U., Takahashi, Y., Settele, J., Díaz, S., Molnár, Z., & Purvis, A. (2022). The direct drivers of recent global anthropogenic biodiversity loss. *Science Advances*, *8*, eabm9982. https://doi.org/10.1126/sciadv.abm9982

Jeanneret, P., Lüscher, G., Schneider, M. K., Pointereau, P., Arndorfer, M., Bailey, D., Balázs, K., Báldi, A., Choisis, J.-P., Dennis, P., Diaz, M., Eiter, S., Elek, Z., Fjellstad, W., Frank, T., Friedel, J. K., Geijzendorffer, I. R., Gillingham, P., Gomiero, T., … Herzog, F. (2021). An increase in food production in Europe could dramatically affect farmland biodiversity. *Communications Earth & Environment*, *2*, 183. https://doi.org/10.1038/s43247-021-00256-x

Kaiser, R. (2021). *Qualitative Experteninterviews: Konzeptionelle Grundlagen und praktische Durchführung, Elemente der Politik*. Springer Fachmedien Wiesbaden. https://doi.org/10.1007/978-3-658-30255-9

Kamp, J., Frank, C., Trautmann, S., Busch, M., Dröschmeister, R., Flade, M., Gerlach, B., Karthäuser, J., Kunz, F., Mitschke, A., Schwarz, J., &

Sudfeldt, C. (2021). Population trends of common breeding birds in Germany 1990–2018. *Journal für Ornithologie*, *162*, 1–15. https://doi.org/10.1007/s10336-020-01830-4

Kehoe, L., Romero-Muñoz, A., Polaina, E., Estes, L., Kreft, H., & Kuemmerle, T. (2017). Biodiversity at risk under future cropland expansion and intensification. *Nature Ecology & Evolution*, *1*, 1129–1135. https://doi.org/10.1038/s41559-017-0234-3

Klebl, F., Parisi, A., Häfner, K., Adler, A., Barreiro, S., Bodea, F. V., Brönnimann, V., De Vries, J. P. R., Dos Santos, A., Hood, A. S. C., Melts, I., Popa, R., Vajna, F., Velado-Alonso, E., & Kernecker, M. L. (2024). How values and perceptions shape farmers' biodiversity management: Insights from ten European countries. *Biological Conservation*, *291*, 110496. https://doi.org/10.1016/j.biocon.2024.110496

Kleijn, D., Kohler, F., Báldi, A., Batáry, P., Concepción, E. D., Clough, Y., Díaz, M., Gabriel, D., Holzschuh, A., Knop, E., Kovács, A., Marshall, E. J. P., Tscharntke, T., & Verhulst, J. (2009). On the relationship between farmland biodiversity and land-use intensity in Europe. *Proceedings of the Royal Society B: Biological Sciences*, *276*, 903–909. https://doi.org/10.1098/rspb.2008.1509

Klein, A.-M., Thompson, A., Lakner, S., Mupepele, A.-C., Paetow, H., Sponagel, C., Bieling, C., Bleidorn, C., Breitkreuz, L., Hasenöhrl, U., Sommer, M., Tanneberger, F., Bruelheide, H., Muus, K., Schmidt, A., Settele, J., & Sporbert, M. (2024). Agrar- und Offenland. In C. Wirth, H. Bruelheide, N. Farwig, J. Marx, & J. Settele (Eds.), *Faktencheck Artenvielfalt. Bestandsaufnehme und Perspektiven für den Erhalt der biologischen Vielfalt in Deutschland* (pp. 217–356). Oekom Verlag.

Kopittke, P. M., Menzies, N. W., Wang, P., McKenna, B. A., & Lombi, E. (2019). Soil and the intensification of agriculture for global food security. *Environment International*, *132*, 105078. https://doi.org/10.1016/j.envint.2019.105078

Kosow, H., Weimer-Jehle, W., León, C. D., & Minn, F. (2022). Designing synergetic and sustainable policy mixes—A methodology to address conflictive environmental issues. *Environmental Science & Policy*, *130*, 36–46. https://doi.org/10.1016/j.envsci.2022.01.007

Leach, M., Scoones, I., & Stirling, A. (2010). Governing epidemics in an age of complexity: Narratives, politics and pathways to sustainability. *Global Environmental Change*, *20*, 369–377. https://doi.org/10.1016/j.gloenvcha.2009.11.008

Leach, M., Stirling, A. C., & Scoones, I. (2010). *Dynamic sustainabilities: Technology, environment, social justice*. Taylor & Francis.

Mack, G., Finger, R., Ammann, J., & El Benni, N. (2023). Modelling policies towards pesticide-free agricultural production systems. *Agricultural Systems*, *207*, 103642. https://doi.org/10.1016/j.agsy.2023.103642

Majer, J. M., Henscher, H. A., Reuber, P., Fischer-Kreer, D., & Fischer, D. (2022). The effects of visual sustainability labels on consumer perception and behavior: A systematic review of the empirical literature. *Sustainable Production and Consumption*, *33*, 1–14. https://doi.org/10.1016/j.spc.2022.06.012

McDonald, R. I., Mansur, A. V., Ascensão, F., Colbert, M., Crossman, K., Elmqvist, T., Gonzalez, A., Güneralp, B., Haase, D., Hamann, M., Hillel, O., Huang, K., Kahnt, B., Maddox, D., Pacheco, A., Pereira, H. M., Seto, K. C., Simkin, R., Walsh, B., … Ziter, C. (2019). Research gaps in knowledge of the impact of urban growth on biodiversity. *Nature Sustainability*, *3*, 16–24. https://doi.org/10.1038/s41893-019-0436-6

McGreevy, S. R., Rupprecht, C. D. D., Niles, D., Wiek, A., Carolan, M., Kallis, G., Kantamaturapoj, K., Mangnus, A., Jehlička, P., Taherzadeh, O., Sahakian, M., Chabay, I., Colby, A., Vivero-Pol, J.-L., Chaudhuri, R., Spiegelberg, M., Kobayashi, M., Balázs, B., Tsuchiya, K., … Tachikawa, M. (2022). Sustainable agrifood systems for a post-growth world. *Nature Sustainability*, *5*, 1011–1017. https://doi.org/10.1038/s41893-022-00933-5

Meuwissen, M. P. M., Feindt, P. H., Spiegel, A., Termeer, C. J. A. M., Mathijs, E., Mey, Y. D., Finger, R., Balmann, A., Wauters, E., Urquhart, J., Vigani, M., Zawalińska, K., Herrera, H., Nicholas-Davies, P., Hansson, H., Paas, W., Slijper, T., Coopmans, I., Vroege, W., … Reidsma, P. (2019). A framework to assess the resilience of farming systems. *Agricultural Systems*, *176*, 102656. https://doi.org/10.1016/j.agsy.2019.102656

Mitter, H., Techen, A.-K., Sinabell, F., Helming, K., Schmid, E., Bodirsky, B. L., Holman, I., Kok, K., Lehtonen, H., Leip, A., Le Mouël, C., Mathijs, E., Mehdi, B., Mittenzwei, K., Mora, O., Øistad, K., Øygarden, L., Priess, J. A., Reidsma, P., … Schönhart, M. (2020). Shared socio-economic pathways for European agriculture and food systems: The Eur-Agri-SSPs. *Global Environmental Change*, *65*, 102159. https://doi.org/10.1016/j.gloenvcha.2020.102159

Möhring, N., Ingold, K., Kudsk, P., Martin-Laurent, F., Niggli, U., Siegrist, M., Studer, B., Walter, A., & Finger, R. (2020). Pathways for advancing pesticide policies. *Nature Food*, *1*, 535–540. https://doi.org/10.1038/s43016-020-00141-4

Moritz, J., Tuomisto, H. L., & Ryynänen, T. (2022). The transformative innovation potential of cellular agriculture: Political and policy stakeholders' perceptions of cultured meat in Germany. *Journal of Rural Studies*, *89*, 54–65. https://doi.org/10.1016/j.jrurstud.2021.11.018

Mupepele, A.-C., Böhning-Gaese, K., Lakner, S., Plieninger, T., Schoof, N., & Klein, A.-M. (2019). Insect conservation in agricultural landscapes: An outlook for policy-relevant research. *Gaia*, *28*, 342–347. https://doi.org/10.14512/gaia.28.4.5

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. (2021). Biodiversity in European agricultural landscapes: Transformative societal changes needed. *Trends in Ecology & Evolution*, *36*, 1067–1070. https://doi.org/10.1016/j.tree.2021.08.014

Nationale Akademie der Wissenschaften Leopoldina, Deutsche Akademie der Naturforscher Leopoldina, & Union der Deutschen Akademien der Wissenschaften (Eds.). (2020). *Biodiversität und Management von Agrarlandschaften: Umfassendes Handeln ist jetzt wichtig: Stellungnahme, Schriftenreihe zur wissenschaftsbasierten Politikberatung*. Deutsche Akademie der Naturforscher Leopoldina e.V. - Nationale Akademie der Wissenschaften.

Newbold, T. (2018). Future effects of climate and land-use change on terrestrial vertebrate community diversity under different scenarios. *Proceedings of the Royal Society B: Biological Sciences*, *285*, 20180792. https://doi.org/10.1098/rspb.2018.0792

O.Nyumba, T., Wilson, K., Derrick, C. J., & Mukherjee, N. (2018). The use of focus group discussion methodology: Insights from two decades of application in conservation. *Methods in Ecology and Evolution*, *9*, 20–32. https://doi.org/10.1111/2041-210X.12860

Osterburg, B., Ackermann, A., Böhm, J., Bösch, M., Dauber, J., de Witte, T., Elsasser, P., Erasmi, S., Gocht, A., Hansen, H., Heidecke, C., Klimek, S., Krämer, C., Kuhnert, H., Moldovan, A., Nieberg, H., Pahmeyer, C., Plaas, E., Rock, J., … Zinnbauer, M. (2023). *Flächennutzung und Flächennutzungsansprüche in Deutschland*. Johann Heinrich von Thünen Institut.

Otero, I., Farrell, K. N., Pueyo, S., Kallis, G., Kehoe, L., Haberl, H., Plutzar, C., Hobson, P., García-Márquez, J., Rodríguez-Labajos, B., Martin, J., Erb, K., Schindler, S., Nielsen, J., Skorin, T., Settele, J., Essl, F., Gómez-Baggethun, E., Brotons, L., … Pe'er, G. (2020). Biodiversity policy beyond economic growth. *Conservation Letters*, *13*, e12713. https://doi.org/10.1111/conl.12713

Outhwaite, C. L., McCann, P., & Newbold, T. (2022). Agriculture and climate change are reshaping insect biodiversity worldwide. *Nature*, *605*, 97–102. https://doi.org/10.1038/s41586-022-04644-x

Parlasca, M. C., & Qaim, M. (2022). Meat consumption and sustainability. *Annual Review of Resource Economics*, *14*, 17–41. https://doi.org/10.1146/annurev-resource-111820-032340

Parot, J., Wahlen, S., Schryro, J., & Weckenbrock, P. (2024). Food justice in community supported agriculture—Differentiating charitable and emancipatory social support actions. *Agriculture and Human Values*, *41*, 685–699. https://doi.org/10.1007/s10460-023-10511-w

Pe'er, G., Finn, J. A., Díaz, M., Birkenstock, M., Lakner, S., Röder, N., Kazakova, Y., Šumrada, T., Bezák, P., Concepción, E. D., Dänhardt, J., Morales, M. B., Rac, I., Špulerová, J., Schindler, S., Stavrinides, M., Targetti, S., Viaggi, D., Vogiatzakis, I. N., & Guyomard, H. (2022). How can the European Common Agricultural Policy help halt biodiversity loss? Recommendations by over 300 experts. *Conservation Letters*, *15*, e12901. https://doi.org/10.1111/conl.12901

Pe'er, G., Zinngrebe, Y., Moreira, F., Sirami, C., Schindler, S., Müller, R., Bontzorlos, V., Clough, D., Bezák, P., Bonn, A., Hansjürgens, B., Lomba, A., Möckel, S., Passoni, G., Schleyer, C., Schmidt, J., & Lakner, S. (2019). A greener path for the EU common agricultural policy. *Science*, *365*, 449–451. https://doi.org/10.1126/science.aax3146

Perino, A., Pereira, H. M., Felipe-Lucia, M., Kim, H., Kühl, H. S., Marselle, M. R., Meya, J. N., Meyer, C., Navarro, L. M., Van Klink, R., Albert, G., Barratt, C. D., Bruelheide, H., Cao, Y., Chamoin, A., Darbi, M., Dornelas, M., Eisenhauer, N., Essl, F., … Bonn, A. (2022). Biodiversity post-2020: Closing the gap between global targets and national-level implementation. *Conservation Letters*, *15*, e12848. https://doi.org/10.1111/conl.12848

Plieninger, T., Draux, H., Fagerholm, N., Bieling, C., Bürgi, M., Kizos, T., Kuemmerle, T., Primdahl, J., & Verburg, P. H. (2016). The driving forces of landscape change in Europe: A systematic review of the evidence. *Land Use Policy*, *57*, 204–214. https://doi.org/10.1016/j.landusepol.2016.04.040

Pohl, C., & Hirsch Hadorn, G. (2007). *Principles for designing transdisciplinary research*. Oekom Verlag. https://doi.org/10.14512/9783962388638

Pröbstl, F., Paulsch, A., Zedda, L., Nöske, N., Cardona Santos, E. M., & Zinngrebe, Y. (2023). Biodiversity policy integration in five policy sectors in Germany: How can we transform governance to make implementation work? *Earth System Governance*, *16*, 100175. https://doi.org/10.1016/j.esg.2023.100175

Qaim, M. (2020). Role of new plant breeding Technologies for Food Security and Sustainable Agricultural Development. *Applied Economic Perspectives and Policy*, *42*, 129–150. https://doi.org/10.1002/aepp.13044

Raven, P. H., & Wagner, D. L. (2021). Agricultural intensification and climate change are rapidly decreasing insect biodiversity. *Proceedings of the National Academy of Sciences of the United States of America*, *118*, e2002548117. https://doi.org/10.1073/pnas.2002548117

Rega, C., Short, C., Pérez-Soba, M., & Luisa Paracchini, M. (2020). A classification of European agricultural land using an energy-based intensity indicator and detailed crop description. *Landscape and Urban Planning*, *198*, 103793. https://doi.org/10.1016/j.landurbplan.2020.103793

Rigal, S., Dakos, V., Alonso, H., Auniņš, A., Benkő, Z., Brotons, L., Chodkiewicz, T., Chylarecki, P., De Carli, E., Del Moral, J. C., Domşa, C., Escandell, V., Fontaine, B., Foppen, R., Gregory, R., Harris, S., Herrando, S., Husby, M., Ieronymidou, C., … Devictor, V. (2023). Farmland practices are driving bird population decline across Europe. *Proceedings of the National Academy of Sciences of the United States of America*, *120*, e2216573120. https://doi.org/10.1073/pnas.2216573120

Rosa, I. M. D., Purvis, A., Alkemade, R., Chaplin-Kramer, R., Ferrier, S., Guerra, C. A., Hurtt, G., Kim, H., Leadley, P., Martins, I. S., Popp, A., Schipper, A. M., Van Vuuren, D., & Pereira, H. M. (2020). Challenges in producing policy-relevant global scenarios of biodiversity and ecosystem services. *Global Ecology and Conservation*, *22*, e00886. https://doi.org/10.1016/j.gecco.2019.e00886

Rosenbloom, D. (2017). Pathways: An emerging concept for the theory and governance of low-carbon transitions. *Global Environmental Change*, *43*, 37–50. https://doi.org/10.1016/j.gloenvcha.2016.12.011

Runge, T. (Hrsg.). (2020). *Innovative Vertragslösungen für die Bereitstellung von Umweltleistungen durch Land- und Forstwirte: Steckbriefe ausgewählter deutscher Fallbeispiele*. Johann Heinrich von Thünen-Institut.

Samnegård, U., Alins, G., Boreux, V., Bosch, J., García, D., Happe, A., Klein, A., Miñarro, M., Mody, K., Porcel, M., Rodrigo, A., Roquer-Beni, L., Tasin, M., & Hambäck, P. A. (2019). Management trade-offs on ecosystem services in apple orchards across Europe: Direct and indirect effects of organic production. *Journal of Applied Ecology*, *56*, 802–811. https://doi.org/10.1111/1365-2664.13292

Seibold, S., Gossner, M. M., Simons, N. K., Blüthgen, N., Müller, J., Ambarlı, D., Ammer, C., Bauhus, J., Fischer, M., Habel, J. C., Linsenmair, K. E., Nauss, T., Penone, C., Prati, D., Schall, P., Schulze, E.-D., Vogt, J., Wöllauer, S., & Weisser, W. W. (2019). Arthropod decline in grasslands and forests is associated with landscape-level drivers. *Nature*, *574*, 671–674. https://doi.org/10.1038/s41586-019-1684-3

Silva, V., Mol, H. G. J., Zomer, P., Tienstra, M., Ritsema, C. J., & Geissen, V. (2019). Pesticide residues in European agricultural soils – A hidden reality unfolded. *Science of the Total Environment*, *653*, 1532–1545. https://doi.org/10.1016/j.scitotenv.2018.10.441

Simkin, R. D., Seto, K. C., McDonald, R. I., & Jetz, W. (2022). Biodiversity impacts and conservation implications of urban land expansion projected to 2050. *Proceedings of the National Academy of Sciences of the United States of America*, *119*, e2117297119. https://doi.org/10.1073/pnas.2117297119

Sims, R., Flammini, A., Puri, M., & Bracco, S. (2015). *Opportunities for agri-food chains to become energy-smart*. FAO and USAID [WWW document]. https://www.researchgate.net/profile/Stefania_Bracco/publication/286623203_Opportunities_For_Agri-Food_Chains_To_Become_Energy-Smart/links/570e09c608aec783ddce6881/Opportunities-For-Agri-Food-Chains-To-Become-Energy-Smart.pdf

Skarbek, C. J., Kobel-Lamparski, A., & Dormann, C. F. (2021). Trends in monthly abundance and species richness of carabids over 33 years at the Kaiserstuhl, southwest Germany. *Basic and Applied Ecology*, *50*, 107–118. https://doi.org/10.1016/j.baae.2020.11.003

Sponagel, C., Weik, J., Feuerbacher, A., & Bahrs, E. (2024). Exploring the climate change mitigation potential and regional distribution of agrivoltaics with geodata-based farm economic modelling and life cycle assessment. *Journal of Environmental Management*, *359*, 121021. https://doi.org/10.1016/j.jenvman.2024.121021

Sponagel, C., Witte, F., & Bahrs, E. (2024). Can markets for nature conservation be successful? An integrated assessment of a product label for biodiversity practices in Germany. *Sustainable Production and Consumption*, *48*, 362–376. https://doi.org/10.1016/j.spc.2024.05.020

Špulerová, J., Petrovič, F., Mederly, P., Mojses, M., & Izakovičová, Z. (2018). Contribution of traditional farming to ecosystem services provision: Case studies from Slovakia. *Land*, *7*, 74. https://doi.org/10.3390/land7020074

Thompson, J., & Scoones, I. (2009). Addressing the dynamics of agri-food systems: An emerging agenda for social science research. *Environmental Science & Policy*, *12*, 386–397. https://doi.org/10.1016/j.envsci.2009.03.001

Timpanaro, G., Scuderi, A., Guarnaccia, P., & Foti, V. T. (2023). Will recent world events shift policy-makers' focus from sustainable agriculture to intensive and competitive agriculture? *Heliyon*, *9*, e17991. https://doi.org/10.1016/j.heliyon.2023.e17991

Tsiafouli, M. A., Thébault, E., Sgardelis, S. P., De Ruiter, P. C., Van Der Putten, W. H., Birkhofer, K., Hemerik, L., De Vries, F. T., Bardgett, R. D., Brady, M. V., Bjornlund, L., Jørgensen, H. B., Christensen, S., Hertefeldt, T. D., Hotes, S., Gera Hol, W. H., Frouz, J., Liiri, M., Mortimer, S. R., … Hedlund, K. (2015). Intensive agriculture reduces soil biodiversity across Europe. *Global Change Biology*, *21*, 973–985. https://doi.org/10.1111/gcb.12752

Unger, M., & Lakes, T. (2023). Land use conflicts and synergies on agricultural land in Brandenburg, Germany. *Sustainability*, *15*, 4546. https://doi.org/10.3390/su15054546

Van Vliet, J., De Groot, H. L. F., Rietveld, P., & Verburg, P. H. (2015). Manifestations and underlying drivers of agricultural land use change in Europe. *Landscape and Urban Planning*, *133*, 24–36. https://doi.org/10.1016/j.landurbplan.2014.09.001

Van Vuuren, D. P., Kok, M. T. J., Girod, B., Lucas, P. L., & De Vries, B. (2012). Scenarios in global environmental assessments: Key characteristics and lessons for future use. *Global Environmental Change*, *22*, 884–895. https://doi.org/10.1016/j.gloenvcha.2012.06.001

Visconti, P., Bakkenes, M., Baisero, D., Brooks, T., Butchart, S. H. M., Joppa, L., Alkemade, R., Di Marco, M., Santini, L., Hoffmann, M., Maiorano, L., Pressey, R. L., Arponen, A., Boitani, L., Reside, A. E., Van Vuuren, D. P., & Rondinini, C. (2016). Projecting global biodiversity indicators under future development scenarios: Projecting biodiversity indicators. *Conservation Letters*, *9*, 5–13. https://doi.org/10.1111/conl.12159

Walz, A., Braendle, J. M., Lang, D. J., Brand, F., Briner, S., Elkin, C., Hirschi, C., Huber, R., Lischke, H., & Schmatz, D. R. (2014). Experience from downscaling IPCC-SRES scenarios to specific national-level focus scenarios for ecosystem service management. *Technological Forecasting and Social Change*, *86*, 21–32. https://doi.org/10.1016/j.techfore.2013.08.014

Weik, J., Lask, J., Petig, E., Seeger, S., Marting Vidaurre, N., Wagner, M., Weiler, M., Bahrs, E., Lewandowski, I., & Angenendt, E. (2022). Implications of large-scale miscanthus cultivation in water protection areas: A life cycle assessment with model coupling for improved policy support. *GCB Bioenergy*, *14*, 1162–1182. https://doi.org/10.1111/gcbb.12994

Weimer-Jehle, W. (2006). Cross-impact balances: A system-theoretical approach to cross-impact analysis. *Technological Forecasting and Social Change*, *73*, 334–361. https://doi.org/10.1016/j.techfore.2005.06.005

Weimer-Jehle, W. (2021). *ScenarioWizard 4.4. Programm zur qualitativen System- und Szenarioanalyse mit der Cross-Impact-Bilanzanalyse (CIB)*. Bedienungsanleitung.

Weimer-Jehle, W. (2023a). *Cross-impact balances (CIB) for scenario analysis: Fundamentals and implementation, contributions to management science*. Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-27230-1

Weimer-Jehle, W. (2023b). *ScenarioWizard 4.53*.

Wesseler, J. (2022). The EU's farm-to-fork strategy: An assessment from the perspective of agricultural economics. *Applied Economic Perspectives and Policy*, *44*, 1826–1843. https://doi.org/10.1002/aepp.13239

Wirth, C., Bruelheide, H., Farwig, N., & Marx, J. M. (2024). *Faktencheck Artenvielfalt.Bestandsaufnahme und Perspektiven für den Erhalt der biologischen Vielfalt in Deutschland. Zusammenfassung für die gesellschaftliche Entscheidungsfindung*. Oekom Verlag. https://doi.org/10.14512/9783987263378

Wirth, C., Bruelheide, H., Farwig, N., Marx, J. M., & Settele, J. (Eds.). (2024). *Faktencheck Artenvielfalt: Bestandsaufnahme und Perspektiven für den Erhalt der biologischen Vielfalt in Deutschland*. Oekom Verlag.

Wüstemann, H., Bonn, A., Albert, C., Bertram, C., Biber-Freudenberger, L., Dehnhardt, A., Döring, R., Elsasser, P., Hartje, V., Mehl, D., Kantelhardt, J., Rehdanz, K., Schaller, L., Scholz, M., Thrän, D., Witing, F., & Hansjürgens, B. (2017). Synergies and trade-offs between nature conservation and climate policy: Insights from the "natural capital Germany—TEEB DE" study. *Ecosystem Services*, *24*, 187–199. https://doi.org/10.1016/j.ecoser.2017.02.008

Zabel, F., Delzeit, R., Schneider, J. M., Seppelt, R., Mauser, W., & Václavík, T. (2019). Global impacts of future cropland expansion and intensification on agricultural markets and biodiversity. *Nature Communications*, *10*, 2844. https://doi.org/10.1038/s41467-019-10775-z

Zurek, M. B., & Henrichs, T. (2007). Linking scenarios across geographical scales in international environmental assessments. *Technological Forecasting and Social Change*, *74*, 1282–1295. https://doi.org/10.1016/j.techfore.2006.11.005

DATA SOURCES

BMEL. (2021). *Flächen für die Rohstoffe der Zukunft*. Bundesministerium für Ernährung und Landwirtschaft [WWW document]. https://www.bmel.de/DE/themen/landwirtschaft/bioeokonomie-nachwachsende-rohstoffe/nachwachsende-rohstoffe-flaechen.html

BMEL. (2023). *Den Wandel gestalten! Zusammenfassung zum GAP-Strategieplan 2023–2027 (Stand: 20. März 2023)*. Bundesministerium für Ernährung und Landwirtschaft [WWW document]. https://www.bmel.de/SharedDocs/Downloads/DE/_Landwirtschaft/EU-Agrarpolitik-Foerderung/gap-strategieplan-kurzueberblick.pdf?__blob=publicationFile&v=4

BMUV. (2022). *Nationale Moorschutzstrategie*. Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz [WWW document]. https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Naturschutz/nationale_moorschutzstrategie_bf.pdf

Böhm, J., De Witte, T., & Michaud, C. (2022). Land use prior to installation of ground-mounted photovoltaic in Germany—GIS-analysis based on MaStR and basis-DLM. *Z Energiewirtsch*, *46*, 147–156. https://doi.org/10.1007/s12398-022-00325-4

Bowler, D. E., Bjorkman, A. D., Dornelas, M., Myers-Smith, I. H., Navarro, L. M., Niamir, A., Supp, S. R., Waldock, C., Winter, M., Vellend, M., Blowes, S. A., Böhning-Gaese, K., Bruelheide, H., Elahi, R., Antão, L. H., Hines, J., Isbell, F., Jones, H. P., Magurran, A. E., … Bates, A. E. (2020). Mapping human pressures on biodiversity across the planet uncovers anthropogenic threat complexes. *People and Nature*, *2*, 380–394. https://doi.org/10.1002/pan3.10071

Dewitz, I., Heinrich-Böll-Stiftung, Bund für Umwelt und Naturschutz Deutschland, & Michael Succow Stiftung zum Schutz der Natur (Eds.). (2023). *Mooratlas: Daten und Fakten zu nassen Klimaschützern: ein Kooperationsprojekt von Heinrich-Böll-Stiftung, Bund für Umwelt und Naturschutz Deutschland und der Michael Succow Stiftung, Partner im Greifswald Moor Centrum*. Heinrich-Böll-Stiftung.

Die Bundesregierung. (2021). *Deutsche Nachhaltigkeitsstrategie. Weiterentwicklung 2021*. Die Bundesregierung.

Dönitz, E., Voglhuber-Slavinsky, A., & Moller, B. (2020). *Agribusiness in 2035—Farmers of the future*. Fraunhofer Institute for Systems and Innovations Research ISI [WWW document]. https://www.isi.fraunhofer.de/content/dam/isi/dokumente/ccv/2020/Agribusiness%20in%202035%20-%20Farmers%20of%20the%20Future.pdf

Eichenberg, D., Bowler, D. E., Bonn, A., Bruelheide, H., Grescho, V., Harter, D., Jandt, U., May, R., Winter, M., & Jansen, F. (2021). Widespread decline in central European plant diversity across six decades. *Global Change Biology*, *27*, 1097–1110. https://doi.org/10.1111/gcb.15447

Eichler, L., & Brühl, C. (2023). Flächenberechnungen zum geplanten Pestizidverbot in Schutzgebieten im Zusammenhang mit der geplanten EU-Verordnung zur "Nachhaltigen Anwendung von Pflanzenschutzmitteln" (Sustainable Use Regulation, SUR) [WWW document]. https://www.ioer.de/fileadmin/user_upload/Presse/Aktuelles/2023/files/20230220_MI_Hintergrundmaterial_IOER_RPTU_Flaechenberechnung-geplantes-EU-Pestizidverbot.pdf

Hallmann, C. A., Ssymank, A., Sorg, M., de Kroon, H., & Jongejans, E. (2021). Insect biomass decline scaled to species diversity: General patterns derived from a hoverfly community. *Proceedings of the National Academy of Sciences of the United States of America*, *118*, e2002554117. https://doi.org/10.1073/pnas.2002554117

Hamilton, H., Henry, R., Rounsevell, M., Moran, D., Cossar, F., Allen, K., Boden, L., & Alexander, P. (2020). Exploring global food system shocks, scenarios and outcomes. *Futures*, *123*, 102601. https://doi.org/10.1016/j.futures.2020.102601

Haß, M., Banse, M., & Deblitz, C. (2020). *Thünen-Baseline 2020–2030: Agrarökonomische Projektionen für Deutschland*. Johann Heinrich von Thünen-Institut.

Haß, M., Deblitz, C., Freund, F., Kreins, P., Laquai, V., Offermann, F., Pelikan, J., Sturm, V., Wegmann, J., de Witte, T., Wüstemann, F., & Zinnbauer, M. (2022). *Thünen-Baseline 2022–2032: Agrarökonomische Projektionen für Deutschland*. Johann Heinrich von Thünen-Institut.

Humpenöder, F., Bodirsky, B. L., Weindl, I., Lotze-Campen, H., Linder, T., & Popp, A. (2022). Projected environmental benefits of replacing beef with microbial protein. *Nature*, *605*, 90–96. https://doi.org/10.1038/s41586-022-04629-w

Meuwissen, M. P. M., Feindt, P. H., Spiegel, A., Termeer, C. J. A. M., Mathijs, E., Mey, Y. D., Finger, R., Balmann, A., Wauters, E., Urquhart, J., Vigani, M., Zawalińska, K., Herrera, H., Nicholas-Davies, P., Hansson, H., Paas, W., Slijper, T., Coopmans, I., Vroege, W., … Reidsma, P. (2019). A framework to assess the resilience of farming systems. *Agricultural Systems*, *176*, 102656. https://doi.org/10.1016/j.agsy.2019.102656

Pe'er, G., Zinngrebe, Y., Moreira, F., Sirami, C., Schindler, S., Müller, R., Bontzorlos, V., Clough, D., Bezák, P., Bonn, A., Hansjürgens, B., Lomba, A., Möckel, S., Passoni, G., Schleyer, C., Schmidt, J., & Lakner, S. (2019). A greener path for the EU common agricultural policy. *Science*, *365*, 449–451. https://doi.org/10.1126/science.aax3146

Pinstrup-Andersen, P. (2018). Is it time to take vertical indoor farming seriously? *Global Food Security*, *17*, 233–235. https://doi.org/10.1016/j.gfs.2017.09.002

Qaim, M. (2020). Role of new plant breeding technologies for food security and sustainable agricultural development. *Applied Economic Perspectives and Policy*, *42*, 129–150. https://doi.org/10.1002/aepp.13044

Schindele, S. (2021). Nachhaltige Landnutzung mit Agri-Photovoltaik: Photovoltaikausbau im Einklang mit der Lebensmittelproduktion: Szenarioanalyse zur Inanspruchnahme landwirtschaftlicher Nutzflächen durch Photovoltaik in Deutschland bis 2050. *GAIA—Ecological Perspectives for Science and Society*, *30*, 96–105. https://doi.org/10.14512/gaia.30.2.7

Silva, V., Yang, X., Fleskens, L., Ritsema, C. J., & Geissen, V. (2022). Environmental and human health at risk—Scenarios to achieve the farm to fork 50% pesticide reduction goals. *Environment International*, *165*, 107296. https://doi.org/10.1016/j.envint.2022.107296

Sponagel, C., Firlus, M., Effenberger, N., Angenendt, E., Bieling, C., & Bahrs, E. (2020). *Perspektiven und Status quo der Eingriffsregelung im Kontext der Landwirtschaft—Das Beispiel der Region Stuttgart*. https://doi.org/10.26084/12DFNS-P008

Statistisches Bundesamt. (2023). *Siedlungs- und Verkehrsfläche wächst jeden Tag um 55 Hektar* [WWW document]. https://www.destatis.de/DE/Presse/Pressemitteilungen/Zahl-der-Woche/2023/PD23_09_p002.html

Statistisches Bundesamt. (2024a). *Landwirtschaftliche Bodennutzung nach ausgewählten Hauptnutzungsarten* [WWW document]. https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Landwirtschaft-Forstwirtschaft-Fischerei/Feldfruechte-Gruenland/Tabellen/flaechen-hauptnutzungsarten.html

Statistisches Bundesamt. (2024b). *Betriebe, Anbauflächen, Erträge und Erntemengen von Gemüse* [WWW document]. https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Landwirtschaft-Forstwirtschaft-Fischerei/Obst-Gemuese-Gartenbau/Tabellen/betriebe-anbau-erntemenge-gemuese.html

Umweltbundesamt. (2023). *Umweltzustand und Trends. Land- und Forstwirtschaft. Landwirtschaft*. https://www.umweltbundesamt.de/daten/land-forstwirtschaft/landwirtschaft#landwirtschaft-heute

Wende, W., Bezombes, L., & Reinert, M.-E. (2018). Introduction of a European strategy on no net loss of biodiversity. In W. Wende, G.-M. Tucker, F. Quétier, M. Rayment, & M. Darbi (Eds.), *Biodiversity offsets* (pp. 5–15). Springer International Publishing. https://doi.org/10.1007/978-3-319-72581-9_2

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Appendix S1. Detailed definition of CIB descriptors.

Appendix S2. Expert-based assessment or CIB matrices.

How to cite this article: Sponagel, C., Thompson, A., Paetow, H., Mupepele, A.-C., Bieling, C., Sommer, M., Klein, A.-M., Settele, J., Finger, R., Huber, R., Albert, C., Filser, J., Jansen, F., Kleemann, J., Schreiner, V., & Lakner, S. (2025). Pathways for biodiversity enhancement in German agricultural landscapes. *People and Nature*, *7*, 2172–2193. https://doi.org/10.1002/pan3.70103