PLANNING LAND USE STRATEGIES: MEETING BIODIVERSITY, CLIMATE AND SOCIAL OBJECTIVES IN A CHANGING WORLD

D4.4. – PATHWAYS FOR MEETING SUSTAINABLE LAND USE STRATEGIES IN 2050

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List of Abbreviations

Term	Description
AECM	Agri-environment-climate measures
AES	Agri-environment schemes
CAP	Common Agricultural Policy
CDE	Communication, Dissemination and Exploitation
CINEA	European Climate, Infrastructure and Environment Executive Agency
CSA	Climate-smart agriculture
DP	Deep ploughing
Dx.x	Deliverable (where x represents the specific number)
EU	European Union
IACS	Integrated administration and control system
LC	Land cover
LUCAS	Land use and coverage area frame survey
LUS	Land use system
M32	Month 32 (contractual delivery month of the project)
NGO	Non-governmental organization
PAT	Precision agriculture technology
PG	Permanent grassland
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PU	Public (dissemination level)
SAC	Special areas of conservation
SME	Small and medium-sized enterprises
SPA	Special protection areas

ToC	Theory of Change
UKRI	UK Research and Innovation
UNCCD	United Nations Convention to Combat Desertification

Executive Summary

Land use is central to many global sustainability challenges, requiring a delicate balance between food security, resource provision, biosphere integrity and climate action. Looking ahead to 2050, transitioning to sustainable land use strategies is critical yet inherently complex due to diverse regional pressures and competing demands. This report aims to navigate this complexity by providing concrete, policy-relevant insights derived from extensive research undertaken across the project's work packages (WP).

The overarching objective of this deliverable is to synthesise diverse findings to guide the development of effective, robust land use policies for the mid-century. To achieve this, the report does not present new primary empirical data but rather employs a methodology known as a second-order meta-analysis. In essence, this approach involves systematically reviewing and synthesizing the key policy messages, quantitative modelling results, and qualitative case study conclusions already generated by previous work packages (WP1, WP2, and WP3). By treating these existing project outputs as data, this synthesis allows for the identification of overarching patterns, common challenges, and high-level opportunities that might not be visible when looking at individual studies in isolation.

A central focus of this synthesis is the identification of 'context-sensitive pathways' towards sustainability. This concept acknowledges that regarding land use policy, a 'one-size-fits-all' approach is rarely effective and often counterproductive. Context-sensitive policies are therefore defined as those specifically tailored to account for unique local realities, including varying environmental baselines, specific socio-economic structures, cultural values, and existing institutional frameworks.

Through this methodical synthesis, the report presents an analysis of barriers and drivers affecting implementation, an examination of policy synergies and trade-offs, and the mapping of these context-sensitive pathways. The synthesis of drivers and barriers suggests that institutional capacity, regulatory coherence, and prevailing economic conditions are the primary factors influencing whether sustainable land use strategies can be successfully implemented.

Furthermore, the analysis of policy synergies and trade-offs highlights a critical dynamic for decision-makers. While some policy interventions can generate positive reinforcing effects across multiple sustainability objectives (synergies), others may lead to conflicting outcomes where progress in one area hinders another (trade-offs), requiring careful negotiation and management. Finally, the analysis emphasises that successfully tailoring policies to local conditions requires a participatory approach that actively involves diverse stakeholders in the design and implementation phases.

Overall, this report provides a comprehensive overview of the critical challenges and opportunities for achieving sustainable land use strategies in 2050, offering actionable, evidence-based insights for policymakers.

What is this deliverable about? This deliverable, produced as part of task 4.4 *Identifying measures to create change* within WP4 *Transformation Pathways for Land Use Strategies* of the PLUS Change project, identifies and summarises the key intervention strategies and pathways required to achieve sustainable land use in Europe by 2050. It traces how interventions across three critical decision levels—governance, land use managers, and individuals (acting as

citizens and consumers)—interact to shape land-use outcomes under various contextual conditions. The main objective of the report is to provide an evidence-based roadmap for designing effective, coherent, and context-sensitive policies by synthesising lessons from past interventions and current literature.

Why it matters? The transition to sustainable land use is a core component of addressing global environmental challenges, specifically climate change mitigation and biodiversity protection; but this should go firmly had-in-hand with improving human wellbeing and fairness. With the European Union's legally binding requirement to reach climate neutrality by 2050, the land sector must transition effectively to meet intermediate and long-term targets. These deliverable matters, because it addresses the implementation gap between high-level strategies—such as the EU soil strategy and the nature restoration regulation—and the practical realities of managing land. It highlights that traditional 'information-incentive' paradigms are often insufficient for sustained change, necessitating a shift toward more potent cognitive and structural frameworks.

Key takeaways and highlights

Governance and policy: Successful sustainable land-use change depends on prioritising environmental goals early in the policy cycle, using varied policy mixes across different regions, and implementing clear, long-term monitoring strategies.

Land use managers: Adoption of sustainable land use practices is primarily limited by financial feasibility and personal beliefs. Change must be driven by providing land managers with long-term, outcome-based incentives and enhanced knowledge transfer to mitigate short-term risks.

Individual behaviour: Psychological approaches that influence people's motivation, such as identity alignment and justification, are significantly more effective than traditional informational or incentive-based strategies. Shifting consumption patterns effectively requires 'choice architecture' and immediate cues provided at the exact point of decision.

Systemic integration: Achieving 2050 goals requires a coordinated strategy where localised behavioural shifts are used as "social proof" to build the public confidence needed for broader structural and regulatory reforms.

What you can do with this (practical applications and who can use the information)

Policymakers at EU, national, and regional levels: Findings can be used to design integrated 'policy packages' that ensure regulatory coherence and distributive justice across affected parties.

Regional planners and practitioners: The report provides a range of tested policy instruments and implementation lessons that can inform the piloting and scaling of interventions in specific local contexts.

Research and project partners: Within the PLUS Change project, these results will directly inform WP5 activities to co-create 'possible landscapes' and transformation pathways that are biophysically viable and socially just.

Stakeholders in the land use system: Practitioners can move beyond simple data-sharing to utilise identity-based commitment loops and 'green-by-default' settings to make sustainable actions the path of least resistance.

Content alignment with other PLUS Change deliverables

The PLUS Change project encourages collaboration and exchange between partners and Work Packages. The content of this Deliverable has integrated work completed across WP 3 and 4, and sets the foundation for empirical work to be conducted in WP5. The content has therefore been developed in alignment with CZECHGLOBE, LEUPHANA, BSC, STICHTING VU, UKF and more. The following table lists the deliverables/milestones that were input for this deliverable and the upcoming deliverables/milestones that this deliverable will contribute to.

Input	Output
D3.2 Report on the Policy Drivers of Land Use Change D3.4 Descriptive land use scenarios to 2050 for European regions D4.1 Intervention points for creating land use policy and decision-making change	D1.2 Planning toolkit D5.1 Report on decision-making and behaviour change in land use managers for sustainable land use D5.2 Practical handbook on intervening in land use systems for sustainable futures
Milestone 8 Theoretically informed research protocol for use by practice cases	Milestone 6 Promising interventions for change identified Milestone 7 Proven interventions identified

1 Introduction

The primary objective of this report is to synthesize diverse research findings generated throughout the project duration to guide the development of effective, robust land use strategies for the mid-century. Achieving sustainability by 2050 requires navigating complex, competing demands for food security, resource provision, biosphere integrity, and climate action. This deliverable aims to cut through this complexity by integrating extensive research undertaken across earlier work packages, moving beyond individual study results to provide overarching, actionable pathways for policymakers facing diverse regional pressures.

To achieve this synthesis without generating new primary data, the report employs a methodology known as a second-order meta-analysis. In essence, this tool allows us to systematically review and integrate the key policy messages, quantitative modelling results, and qualitative case study conclusions already produced by the project, treating these existing outputs as data to reveal high-level patterns and challenges. A central focus of this analysis is the identification of requirements for 'context-sensitive policies'. For a non-familiar audience, this term rejects ineffective 'one-size-fits-all' solutions, defining instead policies that are specifically tailored to account for unique local realities, including varying environmental baselines, socio-economic structures, and cultural values.

1.1 Problem statement

The transition to sustainable land use by 2050 is a crucial component of addressing global environmental challenges, primarily climate change mitigation and biodiversity protection. Within the European Union, the European Climate Law establishes a legally binding framework that requires both Member States and the EU institutions to take all necessary steps to reach climate neutrality by 2050 through reaching net-zero greenhouse gas emission levels, making the land sector a key component of the transition. This long-term objective is supported by a range of complementary EU strategies (such as the EU Soil Strategy for 2030, the EU Nature Restoration Regulation, the EU Biodiversity Strategy for 2030, Forest Strategy, the Fir for 55 Package, the EU Vision for Agriculture and Food and the Farm to Fork Strategy) targeting land, ecosystems, and agriculture, highlighting both the ambition and the complexity of governing land-use change in practice.

1.2 Objective and contribution

The main objective of the report is to provide an evidence-based roadmap for designing effective, coherent, and context-sensitive policies and interventions. By 'context-sensitive', we mean approaches that are specifically tailored to unique social, economic, and institutional settings, acknowledging that uniform solutions rarely yield consistent effects across diverse regions. To achieve this, the report identifies and summarises key intervention strategies and pathways necessary to unlock transformative change towards sustainable land use in Europe by 2050. Specifically, it synthesises lessons from past and current interventions using meta-analyses of land-use governance cases, literature review of adoption factors among land use managers, and a second-order meta-analysis of psychological interventions targeting citizens' and consumers' behaviour (a statistical summary that brings together findings from many pervious research summaries into one overall conclusion).

The report traces how interventions across decision levels in the land-use system—governance, land use managers, and individuals acting as citizens and consumers—shape land-use outcomes under varying contextual conditions (i.e., social, economic, institutional contexts), because the same intervention can produce different outcomes depending on the context and decision level. The term *intervention strategy* is used for concrete, targetable strategies (i.e. policies, actors, interactions), while governance, land-use managers, and citizens/customers are described as decision levels/levels of change. In line with European climate and biodiversity strategies, it examines how coordinated action at these levels can accelerate a transition that simultaneously advances climate mitigation, biodiversity conservation, soil protection and wider well-being goals. In doing so, the report contributes to the ambition of the EU's Eight Environment Action Programme to ensure that people live well within planetary boundaries, in well-being economy where nothing is wasted, growth is regenerative, climate neutrality has been achieved in the Union, and inequalities have been significantly reduced.

To aggregate evidence across intervention strategies, the scope is not restricted to Europe alone. Regional and local decision-makers at EU-level may benefit from this wider evidence as it offers a broader range of tested policy instruments, including implementation lessons of feasibility, compliance and public acceptance, that can inform piloting, scaling, and risk management when transferring interventions to specific local conditions.

1.3 Scope

The report focuses on three intervention strategies in the land-use system that together span the enabling environment (governance), the supply side (land-use managers/producers), and the demand side of sustainable land use (individuals acting as citizens and consumers):

- Governance and land use policy: The full spectrum of policy instruments, regulatory, economic, and institutional, is examined alongside the institutional arrangements through which they are implemented. Attention is given to multilevel and cross-sectoral policy mixes that steer land-use change across Europe, including how coherence, enforcement, and timing shape land-use outcomes.

- Land use managers: This part of the report considers landowners, farmers, foresters, and companies whose decisions determine whether sustainable land-use innovations are adopted in practice. Coverage includes technology-based, ecosystem-based, and socio-economic innovations, and synthesizes key adoption factors that function as barriers, enablers, or drivers depending on context.

- Citizens and consumers: Individual behaviour is addressed in both civic and market roles; as citizens influencing policy through support and activism, and as consumers shaping demand. The focus is on psychological interventions that shift land-relevant behaviours (i.e. food, housing, transport), with particular emphasis on strategies such as social norms and nudges shown to influence choices and strengthen support for sustainable land-use policies.

The scope reflects the close linkage between land-use change, the drivers of climate change and biodiversity loss, and the values and ethics through which land and nature are understood and prioritized in political and economic decision-making. In this report, land use is approached as a set of interacting, linked systems, actors and entities connected through flows of goods, materials, and information, suggesting that sustainability-aligned values can be strengthened through governance arrangements that enable their enactment. Such "leverage points" represent places to intervene in the system. Deeper interventions targeting paradigms and system design offer greater transformative potential and can complement changes that are limited to materials and processes.

1.4 Methods and main findings

The analyses concerning the role of governance in land-use change are based on a meta-analysis of the literature on existing land-use and land-cover changes and land governance. We identified dozens of variables, covering the governance interventions and their implementation, contextual factors, as well as the land-use related outcomes, and developed a codebook to guide case analysis. The analysis of the role of individuals is a second-order meta-analysis of existing meta-analyses that examined the effects of behavioural interventions on various types of individual behaviours that influence (directly or indirectly) land-use change. Finally, the analysis of the role of land-use planners is based on a review of the literature that examines how land managers drive land-use change and what the barriers to this process are.

Our findings suggest that achieving sustainable land use by 2050 necessitates a systemic, coordinated intervention strategy that targets all critical decision-making points within the land use system. Governance and policy must shift towards establishing integrated, multi-level policy packages to ensure regulatory coherence, with success critically dependent on overcoming vested interests and ensuring distributive justice across affected parties. Simultaneously, change on the ground must be driven by providing land managers with long-term, outcome-based incentives and enhanced knowledge transfer, essential for mitigating immediate market failures and the short-term risks associated with sustainable transitions. Finally, the long-term viability of these ambitious reforms rest on engaging citizens and consumers through targeted behavioural science tools to shift consumption patterns and build the strong political will required to enact and sustain robust environmental land-use regulation. Main findings from our analysis are summarised in Table 1.

Table 1. Key Findings

Level of Change	Core finding	Intervention Strategies
1. Governance and Policy	Successful sustainable land-use change relies on prioritizing biodiversity and climate goals early in the policy cycle, adjusting the level of enforcement during implementation, and using long-term monitoring strategies.	-Making clear zoning decisions and prioritizing the primary objectives for different regions -Adopting different policy mixes and approaches across areas -Considering the timing of implementation to avoid anticipated unwanted actions -Defining clear and continuous monitoring strategies and actors in charge of these

		-Considering the available data and methods for monitoring in long-run, establishing a dataset if needed
2. Land Use Managers	Sustainable land use practice adoption is shaped by the combined effects of different factors. Adoption is dominantly constrained by financial feasibility and personal beliefs. A persistent gap between reliable information, advisory systems, and the practical decision-making needs of land users limits uptake. Tailored site-specific interventions that respond to local conditions and user realities are required. Adoption depends on motivational drivers and feasibility-oriented enablers.	-Interventions that influence attitudes, perceived benefits, and expectations while reducing cost, complexity, and uncertainty. -Knowledge enablers: access to education, advisory services, demonstrations, research evidence, and tailored information. -Economic and governance enablers: tailored policies and (financial) support schemes, simplified administrative and regulatory environments. - Social enablers: supportive networks, peer exchange and succession planning.
3. Individuals (citizens and consumers)	Behavioural change of individuals is most effectively driven by cognitive strategies—such as identity alignment and justification—rather than traditional information-incentive models, particularly when targeting discrete, tangible actions. Because localized behavioural shifts do not automatically translate into broader ideological shifts, these interventions should be used as "bottom-up" proof-of-concepts to build the public confidence necessary for systemic reform. In the context of land-use, this requires moving beyond subsidies to prioritize choice architecture and stewardship-based commitments that embed sustainability into the physical and regulatory landscape.	Practitioners should move beyond providing data or rewards by utilizing identity-based commitment loops, encouraging individuals to make public pledges that align sustainable actions with their personal sense of stewardship. These initiatives should leverage choice architecture—such as physical prompts or "green-by-default" settings—at the exact point of decision to make specific, tangible behaviours the path of least resistance. Finally, these localised behavioural shifts should be highlighted as social proof to build the public confidence necessary for broader structural and regulatory reforms.

1.5 Document Structure

The document is organised as follows:

Section 1 – Introduction
Section 2 – Governance
Section 3 – Land use manager level
Section 4 – Individuals
Section 5 – Integration
Section 6 – Conclusion
Section 7 – References

The report is organized into a systematic framework beginning with essential front matter, such as an executive summary, a list of abbreviations, and an introduction that outlines the project's objectives, scope, and general methodology. The core analysis consists of three primary sections—Sections 2, 3, and 4—that examine sustainable land-use change across distinct decision levels. Section 2 addresses governance through a meta-analysis of European case studies, while Section 3 investigates the barriers, enablers, and drivers affecting land-use managers like farmers and foresters. Section 4 focuses on individuals, using a second-order meta-analysis to evaluate the effectiveness of behavioural interventions targeting citizens and consumers. Each of these analytical chapters follows a consistent sub-structure, moving from research objectives and methodology to detailed results and conclusions. Following these individual analyses, Section 5 serves as an integrative chapter that employs a "Theory of Change" framework to connect findings from the three levels into a cohesive pathway toward sustainable 2050 targets. This section maps how interventions in the "enabling environment" (governance), the "supply side" (land managers), and the "demand side" (consumers) interact to produce long-term environmental and social impacts. The report concludes with Section 6, which synthesizes the final findings, followed by a comprehensive reference list in Section 7. Extensive supplementary information is provided in the appendices, including detailed lists of the cases analysed and summary tables of identified barriers and drivers for land-use adoption.

Findings across the three levels of change—governance, land-use managers, and citizens/consumers—are integrated using a 'Theory of Change' framework. A 'Theory of Change' sets out the logic linking actions to impacts by specifying an overreaching if-then proposition: if particular interventions are implemented, then defined outcomes are expected to follow. This logic is represented as an outcome pathway, in which necessary conditions are arranged in a causal sequence: early outcomes serve as preconditions for intermediate outcomes, which in turn enable longer-term outcomes and impacts. The framework makes explicit the assumptions underlying these causal links and provides the basis for synthesising evidence into practical roadmaps that connect short-term instruments and causation to anticipated long-term transformations in sustainable land use.

2 Governance: How governance drives sustainable-land use change in Europe: A meta-analysis of case studies

2.1 Knowledge gap and research objective

Understanding the dynamics and histories of land use and land cover change requires explicit attention to governance. Governance interventions – whether through policies, regulations, or institutional arrangements – have long been recognised as major drivers of land-system change across Europe (Levers et al., 2018; Plieninger et al., 2016). For example, Jepsen et al. (2015) identified institutional reforms (e.g. ranging from EU agricultural policy shifts to the collapse of the Soviet land management paradigm) as the most frequent drivers of land-use change in Europe across several land-management regimes from 1800 to 2010. Likewise, Munteanu et al. (2014) traced agricultural and forest transitions in the Carpathian region to a series of institutional drivers. These findings illustrate that governance is not merely a background condition, but a central force shaping land-use change. At the same time, governance interventions seek to actively steer land-use towards more sustainable trajectories – yet with hugely varying success (e.g. Haensel et al., 2023).

The critical challenge, however, is not only to acknowledge governance as a driver, but also to understand how specific governance interventions affect land-use outcomes. Identifying configurations of policies, institutions, and actors that trigger, enable, or prevent land-system change is essential for selecting effective, efficient, and equitable instruments (Hurlbert et al., 2019). Such insights are especially relevant for landscape types particularly vulnerable to political and economic shocks. For instance, agricultural landscapes have repeatedly been identified as highly sensitive to institutional change (Jepsen et al., 2015; Munteanu et al., 2014, 2017; Pazúr & Bolliger, 2017). In response, diverse policy interventions have been introduced to reduce social and environmental risks and to foster sustainability. The European Union (EU) has implemented agri-environmental schemes to assist farmers in adopting environmentally sustainable land management practices and enhancing biodiversity (Oberlack et al., 2023).

At the same time, efforts to generalise across cases and contexts are gaining prominence. Research on archetypical cause–effect patterns and trajectories of land-use systems seek to reduce complexity by identifying recurring configurations of drivers, while also allowing for regional differentiation (e.g. the adoption of the CAP in Eastern European countries). Yet, as Lambin et al. (2001) highlighted, many explanations of land-use change remain overly simplified. The same land-use transition may have entirely different causes depending on local political, economic, or ecological conditions. This calls for analyses that integrate exogenous and endogenous drivers, while respecting the place-based complexity of human–environment systems.

Despite the prominence of governance in land-system studies, two key gaps remain. First, while systematic reviews exist on particular instruments (e.g. economic tools for sustainable land use: Ackerschott et al., 2023), there is no comprehensive review of the full spectrum of policy instruments for sustainable land-use governance. Second, comparative syntheses across land-use types that evaluates the strengths and weaknesses of governance interventions at different temporal, spatial, and sectoral scales remain limited. Such a synthesis is needed to identify not only intended effects but also unintended consequences, and to ensure greater coherence across policy domains.

Recent comparative research underscores the importance of context. Dingkuhn et al. (2025) contrasted land-use governance in Ireland, Pennsylvania, United States, and the Philippines, showing that regulatory approaches must be combined with "softer" instruments and that intervention points extend beyond farmers to other actors in the food supply chain. They further argue that contextual conditions fundamentally shape the performance of governance interventions, requiring strategic approaches to reconcile conflicting drivers.

Building on this insight, we focus our analysis on Europe. With this, we contribute to answering: (1) *what is the role of governance in driving (sustainable or unsustainable) land-use change in Europe*? And (2) w*hich governance interventions, from which scales of governance, and under which contexts, are effective in achieving sustainable land-use outcomes*? To address these questions, we have conducted a meta-analysis of case studies on land-use governance in Europe. More specifically, our objectives are (1) identifying the diverse configurations of governance interventions across cases targeting specific land use changes; (2) comparing the extent to which these configurations are context-specific or generic across policy settings and institutional environments; (3) evaluating the performance of diverse configurations of intervention elements in shaping sustainable land use and land cover change under different conditions

Ultimately, we aim to identify governance levers and opportunities to foster sustainable land use transitions in Europe. By synthesising lessons from past and current interventions, we seek to inform the design of more effective, coherent, and context-sensitive policies for the future.

2.2 Methodology and data

To gain a nuanced understanding of the cause-and-effect relationships between land use or land cover change and governance interventions, we conducted a meta-analysis aiming to uncover the existing patterns of governance interventions[1]. Building on the literature on existing land use and landcover changes and land governance, we identified dozens of variables, covering the governance interventions and their implementation, contextual factors, as well as the land use related outcomes, and developed a codebook to guide case analysis (shown in Figure 1).

[1] By governance, we refer to the definition in the PLUS-Change Glossary, namely the complex and interactive processes through which societies organize, coordinate, and manage their affairs, and operate towards reaching societal goals. Governance involves the mechanisms, structures, and relationships that facilitate collectively binding decision-making, policy formulation, and implementation. By governance interventions we understand collectively binding decisions, such as laws, policies, plans, ordinances, contracts, regulations, instruments and so forth that may or may not have been produced in a collaborative or participatory way.

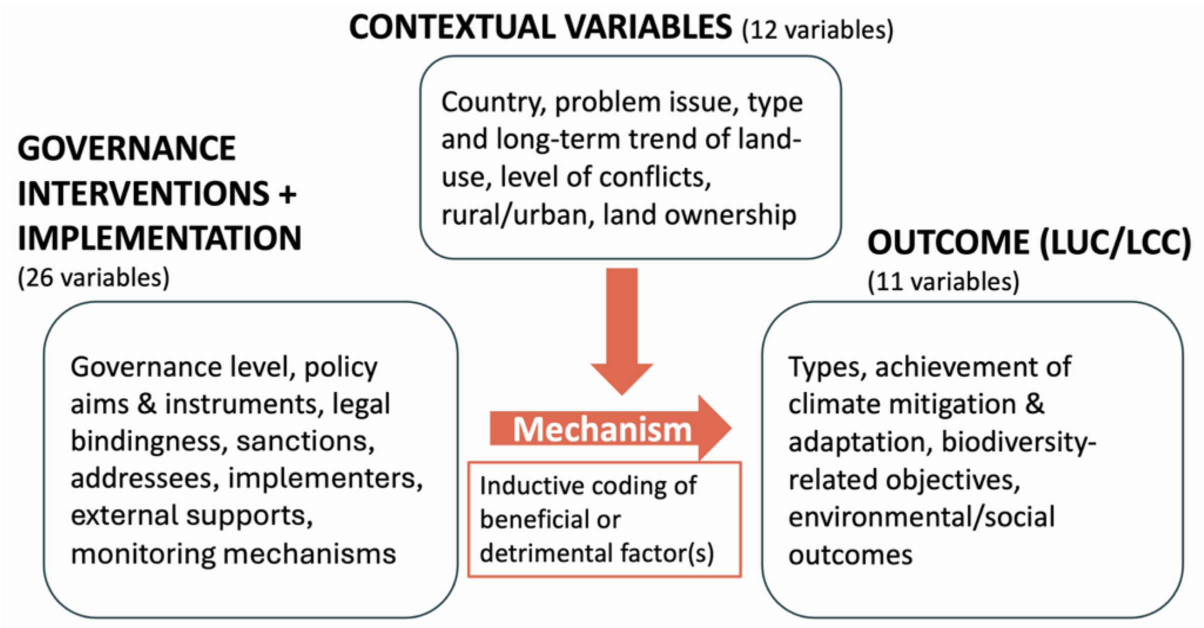

Figure 1. Structure of codebook developed based on existing literature

We conducted a meta-analysis, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure rigor and transparency in the process (Figure 1 and Figure 2). A standardised literature search was conducted on Scopus, with search strings constructed based on (i) the aim of the study, (ii) the particular targets of the PLUS-Change project (biodiversity and climate change-related impacts). Below are the research strings for the meta-analysis:

TITLE-ABS-KEY ("land-use*" OR "landuse*" OR "land use*" OR "land change") AND TITLE-ABS-KEY (governance* OR governing* OR policy* OR policies* OR "planning*") AND TITLE-ABS-KEY (sustainab* OR environmental* OR environment* OR biodiv* OR "climate change" OR (climat* W/2 adapt*) OR (climat* W/2 poli*) OR (climat* W/2 govern*)) AND PUBYEAR > 2004 AND PUBYEAR < 2025 AND SUBJAREA (soci) AND SUBJAREA (envi) AND LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re") AND EXCLUDE (EXACTSRCTITLE , "Sustainability Switzerland") OR EXCLUDE (EXACTSRCTITLE , "Water Switzerland") AND LIMIT-TO (LANGUAGE , "English").

The search results were retrieved on 28 October 2024. The article titles and the abstracts were screened independently by two research assistants to check their eligibility for inclusion.

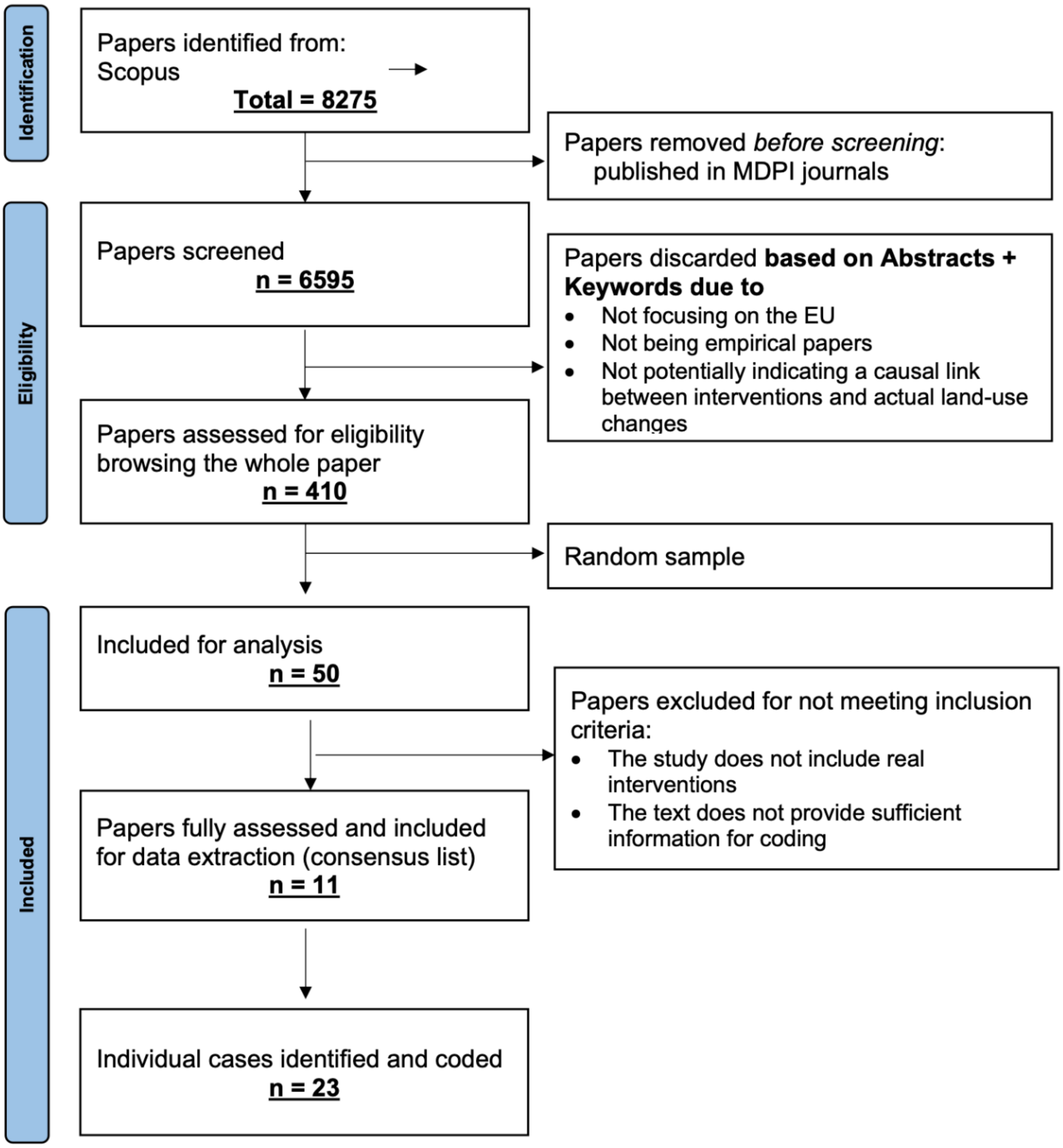

Figure 2. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) for the meta-analysis

Two researchers read the full text of every paper independently and then exchanged and determined the number of cases extracted from each paper. Every paper can cover one or more cases. Identifying the number of cases – and the scope of each case – is a relatively complex matter, given the variety of empirical settings covered in the papers of our sample. Our procedure for delimiting cases in papers was guided by our main research question, namely how governance interventions affect (sustainable) land use change. Our criteria for determining cases within a paper were as follows:

1. **Distinct governance interventions:** If multiple governance interventions are described that are temporally, sectorally or regionally distinct, and if outcomes can be attributed

to these interventions, then each intervention–implementation–outcome–context combination counts as a separate case.

2. **Variation in context:** If the same intervention leads to different outcomes in different contexts (e.g. across regions, landscapes, governance levels, or time periods), then each context–outcome combination is treated as a separate case. Context variation may be ecological (biophysical), socioeconomic, or institutional.

3. **Variation in implementation:** If an intervention leads to different outcomes due to different ways of implementation (e.g. contract duration, levels of enforcement, degrees of uptake), these are considered distinct cases.

4. **Bundling of interventions with similar aims:** If multiple interventions with similar policy aims are described but no differentiation in outcomes is made, these are treated as a single case comprising a bundle of interventions. Bundling is applied when outcomes are reported jointly or when the paper does not provide sufficient detail to disentangle individual contributions. A special case is where interventions interact in a relevant and significant way (either synergistically or antagonistically) with a view to outcomes.

5. **Minimum information threshold:** To qualify as a case, the paper must provide enough detail to identify: (a) the intervention(s) (what governance action was taken), (b) the context (where, when, by whom it was applied), and (c) the outcome(s) (observable effect on land use). Cases that only describe an intervention without an observed effect, or outcomes without some attribution to governance, are excluded.

6. **Exclusions:** We do not code as separate cases: (a) minor mentions of governance with no measurable outcome; (b) speculative or anecdotal claims without evidence; (c) general contextual drivers (e.g. market prices, political regime change) unless directly linked to a governance intervention.

Coding was to be based on evidence from the texts. As a second priority, substantiated judgments by the author(s) that provide good arguments could be drawn on (usually with lower reliability than coding based on evidence). Only as a third priority, coding could be based on informed guesses (e.g. aspects not mentioned in the text, but which could reasonably be assumed given all other information).

Having agreed on the case(s) to assess for each paper, two researchers independently coded each item from the codebook. Afterwards, both researchers met to discuss important differences in coding, with the aim of aligning their understandings of the codebook and ensuring that no relevant information had been overlooked. Importantly, this discussion was not intended to force consensus on individual coding decisions; rather coder-specific interpretations were deliberately retained. This way, apparent coding errors could be eliminated arising from misunderstandings of the codebook. To consolidate coding results, the arithmetic mean of both coders was taken for every item. By comparing the cases derived from a single paper, how a generic concept can be targeted through different policy mixes and approaches across areas over time is uncovered. For example, the 6 cases identified from Haensel et al. (2023) illustrate how combinations of interventions and instruments have influenced permanent grassland preservation in different regions of Bavaria over time. The timing of policy reforms, as well as the timing and extent of protected areas designation, can lead to nuanced differences in preservation outcomes. In the urban context, Brenner et al. (2024) also demonstrate the importance of considering context-dependency when applying interventions to control urban sprawl in dense areas, sprawled areas, as well as isolated building regions.

2.3 Results

Our analysis yields a set of 23 fully coded cases (see Appendix 1 for details). The discussion below presents findings, together with insights from other tasks within Work package 4 *Transformation Pathways for Land Use Strategies* of the PLUS-Change project.

From the 23 coded cases (together with the Theoretically-Informed Research Protocol reports of 12 practice cases), three main categories of actions appear to hold greater potential for achieving sustainable land use governance aimed at biodiversity protection and climate change mitigation or adaptation. These include (1) prioritizing biodiversity and climate goals early in the policy cycle; (2) adjusting the level of enforcement across regions and over time, and (3) employing long-term monitoring strategies (i.e. periodical reporting or dataset development).

Table 2 synthesises three categories of actions and their key barriers and proposed actions emerging from the meta-analysis, with strong theoretical relevance and practical value for sustainable land-use governance addressing three levels of change referring to Deliverable 4.1. *Intervention points for creating land use policy and decision-making change*. At the procedural level, prioritizing environment-oriented targets at the early stage of decision-making underscores the importance of embedding biodiversity and climate objectives into the initial policy framing—supporting theoretical claims that early agenda-setting shapes downstream policy coherence. Contextual intervention points show that adjusting enforcement levels across regions and over time is essential for addressing local heterogeneity in policy objectives, suggesting that flexible and adaptive governance approaches are needed in practice. Finally, the implementation-related point—requiring long-term monitoring strategies—emphasizes the operational capacity needed to sustain interventions over time, aligning with institutional theories on learning and feedback mechanisms. Together, these findings imply that successful interventions require early alignment of goals, context-sensitive enforcement, and investments in data and monitoring systems that support iterative adaptation and accountability.

Table 2. Overview of categories of governance interventions, key barriers and main actions proposed based on the meta-analysis

Levels of change	Categories of governance interventions	Key barriers	Main actions proposed
Procedural	IP1: Prioritizing environment-oriented targets at the early stage of decision-making	Balancing conflicts between economic development and environmental objectives	-Making clear zoning decisions and prioritizing primary objectives for different regions.

Contextual	IP2: Adjusting the level of enforcement across regions and over time	Adapting generic policy objectives to local contexts	-Adopting different policy mixes and approaches across areas -Considering the timing of implementation to avoid anticipated unwanted actions
Implementation	IP3: Requiring long-term monitoring strategies	Determining the forms and methods of clear and regular long-term monitoring	-Defining clear and continuous monitoring strategies and the actors responsible -Considering available data and methods for long-term monitoring, and establishing datasets if needed

These three intervention points, which show high potentials for sustainable land use governance are to some extent aligned with the 4 intervention points for creating land use policy and decision-making change proposed in Deliverable 4.1 *Intervention points for creating land use policy and decision-making change* of the project (see Table 3 for details of these linkages).

Table 3. Comparison between the meta-analysis on sustainable land use governance in D4.4 and other task

Comparison	Categories of governance interventions identified by the meta-analysis on governance level	Intervention points proposed in Deliverable 4.1	
Method	Meta-analysis	Actors' analysis and policy analysis	
Intervention points	IP1: Prioritizing environment-oriented targets at the early stage of decision-making	Procedural	IP1: Enhancing multi-actor participation, equity, and decentralisation in decision-making
			IP2: Bridging policy gaps and enhancing cross-sectoral and cross- scale integration

	IP2: Adjusting the level of enforcement across regions and over time IP3: Requiring long-term monitoring strategies	Contextual	IP3: Responding to external trends and emerging challenges
		Implementation	IP4: Strengthening policy implementation, monitoring, and accountability

However, some limitations need to be acknowledged. Meta-analysis inherently involves trade-off between retaining detailed, case-specific information and ensuring the comparability and codability of the final dataset. To maintain a consistent and analysable dataset, some papers that lacked clear linkages between governance interventions and observed land-use changes had to be excluded from the coding process. This exclusion may have resulted in the loss of potentially insightful findings. While beyond the scope of the present study, future research could explore strategies to better address this trade-off, for example by combining meta-analytic approaches with in-depth case studies.

3 Land use managers

3.1 Introduction

Understanding the factors that influence the adoption of sustainable land use practices is essential not only for robust empirical analysis but also for informing the design of effective, context-sensitive policy interventions. A wide range of factors has been identified in the literature as shaping land use managers' decisions to adopt such practices. Importantly, these factors do not exert a uniform influence: depending on institutional, economic, and socio-cultural contexts, the same factor may function as a driver, an enabler, or a barrier to adoption. Recognising this variability is particularly relevant for policy design, as it highlights the need for tailored instruments rather than one-size-fits-all solutions.

This section builds on the concepts of perceived behavioural control (Ajzen, 1985, 1991) and self-efficacy (Bandura, 1977), which suggest that adoption is more likely when individuals perceive themselves as capable of acting and encounter fewer obstacles. From a policy perspective, this implies that adoption can be supported by measures that strengthen land use managers' perceived capacities, reduced structural and institutional barriers, and align incentives with practical decision-making realities.

This section focuses on factors affecting the adoption of land use innovations by land use managers, including landowners, farmers, foresters, companies, and nature conservation agencies – actors directly working with and managing land. Land use innovations are understood here as the implementation of sustainable land use practices categorised into three distinct groups (Sanz et al., 2017; Swart et al., 2023; Beillouin et al., 2023; Lopez-Rodriguez et al., 2024; WOCAT, 2025):

1. Technology-based innovations – practices that involve the development and application of innovative technologies. Rely on tools, machinery, infrastructure, or scientific innovation. These innovations include:
   1.1. Adapted technologies (e.g. tailored app-based services, climate-smart decision support tools, GIS for mapping, monitoring sensors)
   1.2. Data-based activities (e.g. precision farming, drone-based land assessment)
   1.3. Energy-efficiency & production (e.g. renewable energy sources - solar, biogas, wind, hydropower)
   1.4. Biotechnology & genetic engineering (e.g. improved varieties/breeds)

2. Ecosystem-based innovations – practices that work with and protect natural systems. They mimic, support, or protect natural processes and biological systems. These innovations include:
   2.1. Environmental measures (e.g. flower strips, terraces, alley cropping, forest harvesting-afforestation, area closure)
   2.2. Adapted cropping (e.g. crop rotation, intercropping, species mixture, agroforestry, agrosilvipastoral system)
   2.3. Conservation practices (e.g. reduced tillage, soil conservation, rotational grazing, meadow restoration)
   2.4. Water efficiency (e.g. groundwater and surface water management, drip irrigation, rainwater harvesting, drainage/infiltration ditch)

2.5. General resource/residue use (e.g. seed/plantlets management, waste recycling and composting, litter removal)
2.6. Pesticides efficiency (e.g. Integrated Pest Management)
2.7. Fertilizer efficiency (e.g. soil analysis, controlled-release fertilizers)
2.8. Soil management systems (e.g. cover crops, mulch, natural amendments – green manure, compost, biochar etc.
2.9. Planning and zoning (e.g. windbreak, shelterbelt, fire breaks, removal of alien/ invasive species)

3. Socio-economic innovations – strategies and policies designed to improve the social and economic conditions of people. These innovations include:
   3.1. Regional marketing & value creation (e.g. community-supported agriculture, cooperatives, product certification)
   3.2. Labour productivity (e.g. mechanization and appropriate tools)
   3.3. Diffusion of knowledge (e.g. training, advisory, extension services)
   3.4. Knowledge management (e.g. open-access databases/repository, peer-to-peer learning)

The analysis is guided by the following research question: *How do land use managers decide to implement a sustainable land use practice?* Specifically:

RQ1. Which factors influence a land use manager's decision to adopt a practice?

RQ2. What barriers, enablers and drivers have been identified in the adoption of land use practices (at different stages of adoption)?

3.2 Method

An analysis of academic literature was conducted to identify the factors, barriers, enablers and drivers determining adoption of sustainable land use practice(s).

A combination of keywords and search terms was used to retrieve relevant articles from the Scopus database (search in title, abstract & keywords). The search terms were clustered around seven central themes (see Table 4).

The search was limited to studies in English and original and review articles published in journals.

This search retrieved 1906 records published since 2010. The search results were retrieved on 17 June 2025. Of those, 65 articles were selected for inclusion in analysis based on the title, abstract and keywords of the article. Articles explicitly addressing sustainable land use practice(s) and factors to adopting a practice were included in the selection. Articles that research practice in areas outside of Europe were excluded. Also, articles that discuss adoption of governance practices, measures, incentives or land use planning were excluded.

Table 4. Search terms used in article search

Theme	Keyword strand
Adoption	adopt* OR uptak* OR implement* OR appl* OR integrat* OR use OR usage OR utiliz* OR deploy* OR execut*
Sustainability and justice	sustainable OR climate OR biodivers* OR well-being OR just*
Land use	land*use OR "land manag*" OR agriculture OR "Artificial land" OR bareland OR cropland OR forest* OR grassland OR settlement OR shrubland OR wetland OR woodland OR peatland
Innovation	practic* OR innovat* OR strateg* OR interven*
Influencing factors and enablers	predict* OR determin* OR motiv* OR drive* OR deci* OR behav* OR trigger* OR factor
Barriers	barrier* OR challeng* OR hindrance OR obstacle OR limit* OR gap
Geographical scope	albania OR andorra OR armenia OR austria OR azerbaijan OR belarus OR belgium OR "Bosnia and Herzegovina" OR bulgaria OR croatia OR cyprus OR czechia OR denmark OR estonia OR finland OR france OR georgia OR germany OR greece OR hungary OR iceland OR ireland OR italy OR kazakhstan OR kosovo OR latvia OR liechtenstein OR lithuania OR luxembourg OR malta OR moldova OR monaco OR montenegro OR netherlands OR "North Macedonia" OR norway OR poland OR portugal OR romania OR russia OR "San Marino" OR serbia OR slovakia OR slovenia OR spain OR sweden OR switzerland OR turkey OR ukraine OR "United Kingdom" OR "Vatican City" OR europe*

The full text of 21 articles published between 2013 and 2025 was eventually coded to extract information on the following categories:

- Land use system (LUS)[2],
- Land cover (LC) type[3],
- Sustainable land use practice and its type,
- Adoption factor categories (as per source),
- Barriers (as per source) and their type,
- Enablers (as per source) and their type,
- Drivers and their type,
- Stage of adoption affected.

Table 5 provides an overview of the 21 articles analysed. Most publications are original research or literature reviews, with a smaller number of case studies and one meta-analysis. The majority of articles focus on agriculture, whereas other land use systems are substantially underrepresented (e.g. forestry and peatlands) or not presented at all. A similar imbalance is

[2] Based on PLUS Change Deliverable 3.3 *Handbook on developing integrated scenarios to explore sustainable land use strategies*

[3] According to the classification developed by the Economic Commission for Europe (LUCAS 2018-C3) land cover has 8 main categories, with subclasses (Eurostat, 2018).

evident in the land cover types examined. Most studies address cropland and grassland, with much fewer contributions on woodland, shrubland, or wetlands, and no articles for other land cover types. This agricultural bias restricts understanding of sustainable practice adoption in other land use systems and land cover types, where barriers, drivers, enablers, as well as institutional conditions, and ecological processes may differ significantly.

Table 5. Overview of the articles analysed

Category	Code	Number of articles
Type of study/article	Literature review	10
	Meta analysis	1
	Case study	2
	Original research	8
LUS	Agriculture	20
	Forestry	3
	Peatland	1
LC type[4]	Artificial land	-
	Cropland	19
	Woodland	4
	Shrubland	2
	Grassland	11
	Bareland and lichens/moss	-
	Water	-
	Wetlands	2
Practice type	Technology-based	6
	Ecosystem-based	8
	Socio-economic	2
	A mix of two or more practices	5

Regarding types of practices, the articles mainly analyse ecosystem-based and technology-based innovations, while socio-economic innovations are comparatively less explored, despite their potentially significant role in practice adoption processes.

We distinguished between barriers, enablers and drivers using the following perspective:

A **barrier** is a problem, rule or situation that prevents land use manager from adopting sustainable land use practice, or that makes the adoption impossible (OLD, 2025a).

An **enabler** is an intervention or factor that makes the adoption possible (OLD, 2025b) or facilitates or supports the process of adoption. It helps overcome barriers and makes adoption possible or easier by creating a favourable environment or increased capacity and feasibility of adoption.

[4] The sum is larger than the number of articles, as some articles addressed more than one LC type.

A **driver** is a factor that influences or causes adoption (OLD, 2025c). It is a motivating or triggering factor that provides reason or incentive to adopt. It directly stimulates the decision to adopt by creating a motivation or push to act.

The following typology was created inductively to classify the identified barriers, enablers and drivers into nine thematic categories:

- Biophysical – related to natural conditions, soil, water, climate, or topography;
- Economic – concerns costs, profitability, funding, or market access;
- Environmental – linked to environmental (side-)effects or ecological constraints;
- Governance – arising from institutions, policies, regulations, stewardship or coordination;
- Knowledge – related to skills, education, information, data, or technical know-how;
- Psychological – attitudes, beliefs, perceptions, trust, capacity or motivation;
- Social – peer or family influence, norms, networks, or social acceptance;
- Structural – infrastructure, logistics, or supply chain-related aspects;
- Technical – technology, equipment, implementation feasibility, or maintenance.

These types were based on the overarching themes addressed by the barriers/enablers/drivers rather than on predefined categories. In multiple cases, the barrier was classified as belonging to two different types. In such cases a primary and a secondary type was assigned to it, putting the dominant type first. For example, barrier "Weak or absent social networks and cooperatives" was classified as a social barrier, while barrier "Unfair distribution of knowledge access ("élite capture")" was assigned to Social and Knowledge type.

3.3 Results

Understanding what can affect adoption is important to select an appropriate set of key variables in empirical analysis. It can also support discussion of how the affecting factors can be influenced through policy. Many different **factors** have been identified to influence the land use manager's decision to adopt a sustainable land use practice. We have taken inspiration from Zabala et al. (2025) who conducted a comprehensive literature review focusing on farm adoption of silvopasture and agroforestry. They categorised the factors into three blocks and nine broad groups:

1. External/contextual factors:
   a. Farm characteristics:
      i. Land (endowment and tenure security);
      ii. Biophysical characteristics;
      iii. Quantity of farm production;
      iv. Livelihood – strategies related to the farm cycle (e.g. livelihood diversity, crop diversity, main occupation, major crops etc.)
      v. Pathways – past experience, previous adoption history, current practices, future prospect of the farm in the business and successor factor, i.e. future expectations about the farm and whether heirs will continue farming.
   b. Household characteristics:
      i. Demographics – family size, household age and available labour;

    - ii. Income and socioeconomic status – mean income, wealth level, loans, savings, remittances
  - c. Factors related to institutions, including policies to promote innovation adoption – institutional transparency, incentives and facilitation of participatory processes.
  - d. Social context:
    - i. Engagement in social networks – participation in collective action events, membership of associations, contacts outside the community;
    - ii. Social influence (norms and pressure) – what others do (descriptive norms), what others think one should be doing (injunctive norms), and an individual's willingness to keep social cohesion.
2. Factors related to the practice:
   - a. Knowledge – access to the amount, quality and flows of information (including trust in the source of information);
   - b. Technical feasibility – complexity of the innovation, compatibility with farmer's previous experience and knowledge, compatibility with farm priorities and practices;
   - c. Economic rationality – cost and benefits of the practice (profitability), access to credit, and macroeconomic context (markets).
3. Factors intrinsic to the individual:
   - a. Objective individual characteristics – age, gender, marital status, education, health status;
   - b. Subjective individual characteristics:
     - i. Beliefs, values, interests and personal norms – stewardship motivation, doing what is considered right, not feeling guilty about one's own choices, cultural values, fulfilling various livelihood welfare objectives simultaneously, individual aspirations, plans for the future, and psychic income from the activity (personal satisfaction, happiness, well-being and emotional benefits arising from performing the activity);
     - ii. Perceptions – awareness of the seriousness of the problem perception of the technology, perception about time-lags and time-discounting, risk perception and self-efficacy.
     - iii. Attitudes – e.g. towards risk, the environment, information gathering, management styles, confidence in interpreting information, experimenting, and regarding engagement with policy instruments.
     - iv. Behavioural intention and motivation.

We have identified several other studies that present factors that influence the adoption of sustainable land use practice, however the Zabala et al. (2025) study is the most recent and most comprehensive one. We acknowledge that some other factors may appear in studies focusing on other land use systems or other land use practices.

These factors can influence the adoption of sustainable land use practices, however the direction of the influence can vary, i.e. a factor can act either as a driver or as a barrier for adoption.

3.3.1 Barriers

In total, 278 quotes mentioning different barriers were extracted from the articles. Most frequently, knowledge, economic and psychological barriers to adopting sustainable land use practice have been mentioned, followed by governance, structural and social barriers (see Figure 3 and Appendix 2). The subsequent part of this section provides detailed descriptions of the identified barriers, ordered by their prominence in the analysed literature, as reflected by the frequency with which they were mentioned in the analysed literature.

	Biophysical	Economic	Environmental	Governance	Knowledge	Psychological	Social	Structural	Technical
Biophysical	12								
Economic	7	34		4	7	1		4	2
Environmental	1		8			1			
Governance				23		2			
Knowledge				1	41	4		16	
Psychological						38	4		8
Social					1	12	8		
Structural		15		1				7	
Technical									16

Figure 3. Barrier frequency per type – number of barriers mentions extracted from articles (the types listed on the left column indicate the dominant type of the barrier, while those on the top row - the secondary type of the barrier)

Knowledge barriers relate both to the characteristics of sustainable land use practices (e.g. information availability, quality, and trust) and to intrinsic factors among land managers (skills, education, knowledge, and perceptions). *Lack of knowledge, skills, and technical capacity* is one of the most frequently reported constraints on adoption. Limited understanding of ecological processes, unfamiliarity with specific techniques, and insufficient digital or technical competences reduce confidence and willingness to experiment with new management approaches (Klebl et al., 2023; Gemtou et al., 2024). Sustainable or climate-smart options are often seen as complex, requiring advanced technical ability, specialised equipment, or new decision-making skills (Moxley et al., 2021; Heller et al., 2024). This challenge is particularly pronounced for digital and precision agriculture, where non-adopters report difficulties managing tools and interpreting data (Pierpaoli et al., 2013; Parra-Lopez et al., 2024). Higher levels of formal education and training are associated with greater adoption, while low education and limited advisory support constrain implementation, creating a gap between motivation and practical ability (Mills et al., 2017; Rizzo et al., 2023).

A further barrier is the *limited evidence base and insufficient research on the long-term environmental and productivity effects* of sustainable land use practices. Many land managers seek reliable, context-specific evidence before modifying established production systems, and weak or inconclusive data heightens perceptions of risk (Gemtou et al., 2024). Research on several emerging systems remains geographically narrow or too short to assess enduring impacts on soil carbon, biodiversity, or greenhouse gas emissions, making trade-offs difficult to evaluate (Markiewicz-Keszycka et al., 2023). In some cases, environmental benefits are viewed as overstated or not sufficiently tested, which undermines trust and reduces willingness to invest time and resources (Button et al., 2022). This barrier is especially evident in carbon-sequestering soil interventions, mixed grazing, and agroforestry, where evidence gaps reduce clarity about expected outcomes and suitability across different contexts (Markiewicz-Keszycka et al., 2023).

Also important is *lack of awareness or shared understanding of environmental challenges, policy frameworks, and benefits*. When land managers do not perceive current practices as environmentally harmful, the incentive to transition is reduced (Karali et al., 2014). Awareness is strongly linked to perceptions of urgency: those better informed about sustainability challenges are more likely to understand the need for change and acknowledge potential benefits (Gemtou et al., 2024). In several contexts, limited familiarity with schemes such as peatland restoration or carbon certification has constrained participation (Moxley et al., 2021; Cammarata et al., 2024). Confusion about environmental processes, including distinctions between carbon transfer and long-term sequestration, further complicates assessments of sustainability, while uneven recognition of ecological priorities reinforces fragmented awareness (Button et al., 2022; Carretero-Paulet et al., 2025).

Two interrelated knowledge-related barriers are *lack of access to reliable, understandable information* and *lack of trust in information sources, technologies, or scientific evidence*. Overly technical, incomplete, or difficult to interpret information creates confusion and hinders evaluation of whether practices are relevant or beneficial in local conditions (Karali et al., 2014; Klebl et al., 2023). Limited access to clear information restricts understanding of performance, risks, and trade-offs (Olum et al., 2019; Gemtou et al., 2024). Trust issues arise when research appears contradictory, insufficiently applicable to local contexts, or linked to concerns about data use in digital technologies (Barnes et al., 2019; Gemtou et al., 2024). Under these conditions, farmers may rely instead on personal experience or peer networks.

Both barriers are reinforced by a *lack of expert advice or technical support*, as advisory and extension services are often necessary to interpret evidence and contextualise knowledge (Barnes et al., 2019; Gemtou et al., 2024). Where advisors are scarce or lack relevant expertise, decision-making is more uncertain and adoption less likely (Adamsone-Fiskovica and Grivins, 2024; Rouet-Leduc et al., 2024). Limited opportunities for hands-on learning and follow-up support further exacerbate reluctance to change (Rizzo et al., 2023; Masi et al., 2022). When reliable information is inaccessible, trust is low, and expert advice is limited, sustainable land use practices may appear risky or inappropriate, constraining wider uptake.

Other knowledge barriers include provision of information which is not synchronized with farm-management cycles, lack of continuous learning or outdated knowledge and need for dedicated training.

Economic barriers reflect factors related to sustainable land use practice (e.g. costs, benefits, access to credit and markets) and external/contextual conditions (e.g. quantity of farm production). *Economic and financial constraints and uncertainty of returns* are central to reluctance toward adoption. Concerns about income loss from production restrictions and the need for subsidies to offset reduced earnings have been widely reported (Karali et al., 2014). Uncertainty about the profitability of new technologies or practices strongly influences investment decisions, particularly when technologies are costly and returns vary across farms (Barnes et al., 2019). Difficulty assessing the rate of return or distrust of experimental evidence further discourages uptake. Perceived costs and benefits shape decisions, with farmers highlighting investment requirements, potential yield reductions, higher workloads, training needs, and long payback periods (Gemtou et al., 2024). Income losses associated with restoration or conservation actions have been cited as a barrier, especially in smaller farms with limited financial resilience (Moxley et al., 2021; Cammarata et al., 2024). When foregone benefits exceed compensation, adoption becomes unlikely (Klebl et al., 2023).

High initial investment costs are consistently identified as a key barrier. Upfront expenses for specialised machinery, equipment, or technology required for conservation or precision agriculture hinder adoption, particularly among small farms (Barnes et al., 2019; Heller et al., 2024). High transaction costs within biodiversity schemes and expensive peatland restoration measures are reported to reduce uptake without substantial public support (Klebl et al., 2023; Moxley et al., 2021). In precision agriculture, perceived high investment cost and limited access to appropriate technology remain significant obstacles, with adoption strongly linked to income levels (Petrovic and Csambalik, 2025).

Another frequently reported economic barrier concerns *reduced yields and productivity losses*. Land managers may expect reduced production areas or lower yields, with direct consequences for income (Dias de Souza et al., 2025). Some systems are perceived as reallocating carbon to roots at the expense of harvestable biomass, reinforcing fears of lower marketable output (Button et al., 2022). Even when practices reduce labour or fuel needs, potential yield reductions and financial risks lead to scepticism about long-term economic performance (Heller et al., 2024). Studies of perennial systems indicate only marginal profit improvements, insufficient to justify transition where financial margins are already narrow (Parra-Lopez et al., 2024).

Two interrelated and often mentioned economic barriers are *distance to markets, suppliers, and services* and *limited market development and awareness for new or alternative crops*. Remote farm locations increase transportation and transaction costs, constrain access to competitive prices, and reduce availability of essential inputs and financial services (Petrovic and Csambalik, 2025). Inadequate access to stable or functioning markets has hindered adoption in multiple contexts (Adamsone-Fiskovica and Grivins, 2024), especially when weak institutional coordination compounds these structural constraints (Masi et al., 2022). Limited or underdeveloped markets for novel crops further reduce incentives, as low or uncertain demand undermines willingness to change practices (Gemtou et al., 2024). In some cases, insufficient market outlets for organic or certified products have led to scheme withdrawal (Markiewicz-Keszycka et al., 2023). Products lacking recognised labelling or certification may not achieve price premiums (Heller et al., 2024), and promising crops may remain underexploited due to low market awareness, as seen with moringa (Carretero-Paulet et al., 2025).

Other often mentioned economic barriers include unequal distribution of benefits and financial burdens, limited access to credit, constrained financial support (low compensation, misaligned incentives), economic constraints due to globalization and market forces, and lower income.

Psychological barriers reflect subjective factors intrinsic to the individual, such as beliefs, perceptions, attitudes, and behavioural control. Among these, *older age and experience-based reliance* is the most frequently reported barrier. Long-established routines and knowledge systems may make new practices appear unnecessary, risky, or difficult to integrate. Many studies indicate a negative association between age and adoption, with lower uptake among farmers over 65 and higher adoption rates among younger farmers who are generally more willing to explore unfamiliar solutions and technologies (Barnes et al., 2019; Klebl et al., 2023; Gemtou et al., 2024). In some contexts, this barrier has been highlighted specifically in transitions to organic farming, agri-environmental cropping, and climate-smart agriculture (Adamsone-Fiskovica and Grivins, 2024; Petrovic and Csambalik, 2025). In addition to age, health limitations may reduce willingness to change management practices (Karali et al., 2014).

A technology-related psychological barrier is *perceived complexity or low usefulness of technologies and innovations*. Adoption is less likely when farmers do not perceive a clear advantage or compatibility with existing systems (Rizzo et al., 2023). Complexity and unfamiliarity (e.g. difficulties operating digital tools or managing multiple devices) increase insecurity and contribute to technology aversion (Pierpaoli et al., 2013; Masi et al., 2022).

Perceived risks and risk aversion also shape decisions. Many farmers explicitly associate success with minimizing risk (Karali et al., 2014), making them cautious toward practices that could jeopardize production or income. Risk aversion is linked to resistance to departing from established methods, and insufficient information can heighten fear of negative outcomes (Dias de Souza et al., 2025; Gemtou et al., 2024). Uncertainty surrounding digitalisation, including data and performance risks, can intensify this reluctance (Parra-Lopez et al., 2024).

Adoption may further be hindered by *established productivist mindsets and resistance to change*, particularly where farmers view maximising agricultural output as a core value (Mills et al., 2017). Productivists´ orientations are shaped by motives such as yield, income, product quality, cultural heritage, and social identity (Gemtou et al., 2024). These established views can make environmental management appear incompatible with farming objectives and difficult to internalise (Swart et al., 2023).

Negative or ambivalent views toward sustainability manifest in *negative attitudes towards sustainable practices*. Farmers may be sceptical of the relevance or economic consequences of such practices, including fears of reduced productivity (Markiewicz-Keszycka et al., 2023). Cultural expectations and inherited practices can reinforce reluctance, particularly when change is perceived as radical or at odds with traditional landscapes and identities (Moxley et al., 2021).

A further barrier is *low self-efficacy, reinvention capacity, or confidence*, which reduces farmers' belief in their ability to implement or adapt new approaches. Adoption is more likely when farmers perceive sufficient skills and resources to modify practices to their conditions (Klebl et al., 2023; Rizzo et al., 2023). A lack of ownership or responsibility, combined with prevailing attitudes and social norms, may also diminish confidence and reduce motivation to adopt (Swart et al., 2023).

Other psychological barriers mentioned in the literature include intention-behaviour gap and resistance to behavioural change, social disapproval or pressure for production efficiency, distrust or disengagement due to interference or past experiences, historical resentment ("good land should produce food") and preference for "tidy" landscapes.

Among **governance barriers**, the most frequently cited is an *unsupportive or unclear legal framework*. Policies hinder adoption when they are misaligned with local conditions, impose administrative burdens, fail to compensate income losses, lack payment differentiation, or do not provide a long-term strategic vision (Gemtou et al., 2024). Agri-environmental contracts are particularly challenging where guidelines are unclear, inconsistent, or unstable (Klebl et al., 2023). A predominantly productivist policy orientation may overlook diverse motivations for adoption (Swart et al., 2023). Eligibility rules may exclude groups such as commons or rewilding managers, who must seek alternative financing (Rouet-Leduc et al., 2024). Conflicting messages about food production and environmental management (Mills et al., 2017), legal uncertainties in areas such as herbicide regulation (Heller et al., 2024) or carbon-rich soil amendments (Button et al., 2022), and weak institutional coordination (Masi et al., 2022) further constrain adoption.

Another governance barrier is *high bureaucratic burden and inflexible administrative procedures in support schemes*. Application processes for agri-environment and organic farming schemes are perceived as time-consuming and costly, with compensation often seen as too low relative to administrative effort (Karali et al., 2014). Certification and subsidy requirements demand substantial time, skills, and knowledge, discouraging participation where procedures are viewed as excessive or rigid (Gemtou et al., 2024). Higher workloads and bureaucratic demands are consistently associated with lower uptake of measures (Klebl et al., 2023).

Top-down policy design with little farmer input, land tenancy or tenant insecurity, and lack of coordination between public and private sectors are other governance barriers found in literature.

Structural barriers relate to contextual features such as farm size, labour availability, and infrastructure. *Farm size limitations* restrict the financial, technical, and organisational capacities needed for sustainable land use practice adoption. Larger farms benefit from economies of scale, lower unit costs, and higher investment returns, making it easier to adopt precision or climate-smart technologies (Barnes et al., 2019; Gemtou et al., 2024; Parra-Lopez et al., 2024). Small farms, by contrast, may lack financial or technical resources and face high certification and investment uncertainties (Cammarata et al., 2024). Many emerging technologies are oriented toward large-scale systems, reinforcing disparities in uptake (Parra-Lopez et al., 2024). Farm size may also limit feasibility of landscape-level sustainability measures, and farms considered "too small" may face practical constraints when transitioning to substantially different systems, including forestry (Markiewicz-Keszycka et al., 2023).

High labour demands and shortage of a skilled workforce further interact with size-related constraints. Fixed family labour supplies can make new practices appear inflexible and difficult to integrate (Karali et al., 2014). Labour shortages are reinforced by low education levels, limited advisory support, and unfavourable working conditions (Rizzo et al., 2023), while a lack of workers capable of carrying out specialised or traditional practices creates uncertainty about system continuity (Rouet-Leduc et al., 2024). Increased workload and time pressure also hinder the uptake of specific practices, including cover cropping (Adamsone-Fiskovica and Grivins, 2024).

Additional structural barriers include insufficient physical and digital infrastructure (e.g. roads, irrigation, communications).

The dominant **social barrier** is *weak or absent social networks and cooperatives*. Limited access to peer knowledge and support reduces opportunities for mutual learning and participation in environmental measures (Karali et al., 2014). Social networks influence decisions when land managers follow practices adopted by trusted peers, especially where networks are supportive of climate-smart or biodiversity-friendly approaches (Gemtou et al., 2024). Isolation from other land managers undermines adoption by restricting comparison, knowledge exchange, and support (Klebl et al., 2023; Rizzo et al., 2023).

Socio-psychological barriers such as *social norms and peer influence* also affect adoption. Perceived peer expectations shape behaviour, and concerns about social judgement may discourage experimentation (Heller et al., 2024). Peer environments and existing farm-level technologies are associated with higher probabilities of adopting sustainable or precision practices (Barnes et al., 2019; Swart et al., 2023). Heterogeneity in willingness and ability to change further reflects varied social contexts and identities (Mills et al., 2017).

At the same time, the *absence of successors on family farms and youth disinterest in farming* reduces incentives for long-term investment. Farmers close to retirement may be reluctant to adjust their systems when no successor is expected (Karali et al., 2014). Conversely, succession planning increases willingness to adopt new practices, as long-term benefits become more meaningful when a future farmer is anticipated (Gemtou et al., 2024).

Technical barriers fall into three broad themes: complexity or incompatibility of innovations and technologies, technology limitations, and trade-offs and unintended technological effects.

Complexity or incompatibility of innovations and technologies arises when new technologies are viewed as too complex, impractical, or insufficiently adapted to local farm conditions. Studies report difficulties integrating technologies and innovation processes into daily management (Gemtou et al., 2024), concerns over poor practicality in implementation (Rouet-Leduc et al., 2024), and challenges adapting exotic or underutilised crops to specific environments (Carretero-Paulet et al., 2025). These findings reinforce that one-size-fits-all solutions are unlikely across diverse farm contexts (Markiewicz-Keszycka et al., 2023).

Technology limitations include missing, inadequate, or inaccessible technological resources, such as insufficient genomic tools for breeding wild or novel species (Carretero-Paulet et al., 2025), limited access to appropriate machinery or technology (Petrovic and Csambalik, 2025), and constraints in applying practices on organic soils (Button et al., 2022). Implementation barriers also arise from agronomic challenges such as uneven crop maturity, which complicates operations (Adamsone-Fiskovica and Grivins, 2024).

Trade-offs and unintended technological effects occur where technologies introduce new agronomic or socio-economic challenges. Reported examples include cover crops acting as weeds in subsequent seasons (Dias de Souza et al., 2025), restrictions on manure incorporation in no-till systems (Heller et al., 2024), long establishment periods in grazing systems (Markiewicz-Keszycka et al., 2023), and mechanization reducing employment opportunities (Rouet-Leduc et al., 2024).

Biophysical barriers relate to physical and ecological characteristics of farms. *Climatic limitations*, such as drought, restricted water availability, short growing seasons, or insufficient sunlight, constrain the feasibility of sustainable practices (Karali et al., 2014; Dias de Souza et al., 2025). Cold climates may reduce crop growth and limit the effectiveness of practices like cover cropping, agroforestry, and buffer zones (Heller et al., 2024; Markiewicz-Keszycka et al., 2023).

Biophysical constraints and features of farms (e.g. soil type or quality, topography) further restrict adoption. Steep or erosion-prone land may be unsuitable for specific production systems, such as organic arable farming (Karali et al., 2014), while clayey soils with high water retention and low spring temperatures can delay sowing and impede conservation agriculture (Heller et al., 2024). Stone-rich soils, unfavourable subsoils, or shallow rooting layers may make land appear unsuitable for environmental management (Button et al., 2022), contributing to a gap between willingness and ability to adopt sustainable practices (Mills et al., 2017).

Environmental barriers primarily involve *trade-offs and unintended environmental effects* that arise when ecological outcomes are uneven, context-specific, or counterproductive. Natural regrowth or unmanaged buffer zones may not provide expected ecosystem services if their size or density is insufficient (Dias de Souza et al., 2025), while some biodiversity-enhancing measures benefit certain species but negatively affect others (Markiewicz-Keszycka et al., 2023). Concerns also arise that potential carbon benefits from peat or soil management practices may be offset by carbon losses through respiration or other emissions (Button et al., 2022). Measures involving water table manipulation to reduce carbon losses must be carefully managed to avoid negative co-effects such as reduced yields, machinery limitations, unstable soil conditions, flooding risks, or increased nitrous oxide and methane emissions (Button et al., 2022).

As a result, 69 unique barriers to sustainable land use practice adoption were identified in the literature (see Table 6). The largest group consists of economic barriers (17), reflecting issues related to costs, financial support, market access, and income stability. A substantial number of psychological barriers (15) were also identified, encompassing beliefs, trust, values, perceptions, attitudes, and factors linked to age, experience, and self-efficacy. A further 13 barriers are knowledge- and skill-related, including access to reliable and timely information, awareness of environmental challenges, and availability of continuous learning opportunities, expert advice, and advisory support. Governance, social, and structural barriers are less diverse but still significant. Governance barriers (6) involve the design, coordination, and implementation of policies, legal frameworks, and administrative procedures. Social barriers (6) relate to social networks, peer influence, public attitudes, social norms, and intergenerational issues such as land succession. Structural barriers (5), though potentially overlapping with other categories, stand out due to their cross-cutting nature, including constraints linked to infrastructure, labour availability, and farm size or specialisation. The least diversity was found for biophysical (2), environmental (3), and technical (3) barriers, which reflect climatic, biophysical, and technological limitations and trade-offs.

Table 6. List of identified barriers per type (in alphabetical order)

Barrier / Barrier type	Biophysical	Economic	Environmental	Governance	Knowledge	Psychological	Social	Structural	Technical
Number of barriers	**2**	**17**	**3**	**6**	**13**	**14**	**6**	**5**	**3**
Absence of successor and youth disinterest in farming							■		
Biophysical constraints and features of farms	■								
Climatic limitations (temperature, water, growing season)	■								
Complexity or incompatibility of innovations and technologies									■
Conflict between economic goals and sustainability		■							
Constraints in financial support (low compensation, misaligned incentives)		■							
Cultural or historical beliefs resisting change						■			
Distance to markets, suppliers, and services		■							
Distrust/disengagement due to interference or past experiences						■			
Economic constraints (globalization, market forces)		■							
Economic implications insufficiently studied		■							
Economic/financial constraints and uncertainty of returns		■							
Established productivists´ mindsets and resistance to change						■			
Farm size limitations								■	
Food security concerns override environmental priorities				■					
High bureaucratic burden and inflexible administrative procedures in support schemes				■					
High cost of training courses		■							
High initial investment costs		■							
High labour demands and shortage of skilled workforce								■	
High-intensity production models limiting diversification								■	
Historical resentment (“good land should produce food”)						■			
Incompatibility of payment levels with specific site conditions and farm specialisation		■							

Barrier / Barrier type	Biophysical	Economic	Environmental	Governance	Knowledge	Psychological	Social	Structural	Technical
Information not synchronized with farm-management cycles					■				
Intention-behaviour gap and resistance to behavioural change						■			
Irreversibility of land-use change (agriculture to forestry)			■						
Knowledge gap between machine suppliers and user ability					■				
Lack of access to reliable, understandable information					■				
Lack of awareness or shared understanding of environmental challenges, policy frameworks, and benefits					■				
Lack of baseline biodiversity data for long-term monitoring					■				
Lack of continuous learning / outdated knowledge					■				
Lack of coordination between public & private sectors				■					
Lack of expert advice or technical support					■				
Lack of feedback or recognition for environmental efforts						■			
Lack of financial literacy and bureaucratic competence					■				
Lack of infrastructure (internet, irrigation, roads, communication)								■	
Lack of knowledge, skills, and technical capacity for sustainable land use practices					■				
Lack of perceived environmental benefits			■						
Lack of trust in information sources, technologies, or scientific evidence					■				
Land tenancy or tenant insecurity				■					
Limited access to credit and financial constraints		■							
Limited evidence base and insufficient research on long-term environmental and productivity effects					■				
Limited market development and awareness for new or alternative crops		■							
Limited R&D and breeding resources					■				
Low attractiveness of forestry as diversification						■			
Low self-efficacy, reinvention capacity or confidence						■			
Lower income		■							

Barrier / Barrier type	Biophysical	Economic	Environmental	Governance	Knowledge	Psychological	Social	Structural	Technical
Need for dedicated training					■				
Negative attitudes towards sustainable practices						■			
Negative public attitude toward herbicide use							■		
Older age and experience-based reliance of farmers contributing to resistance to change						■			
Part-time farmer status								■	
Perceived complexity or low usefulness of technologies and innovations						■			
Perceived payback		■							
Perceived risks / risk aversion						■			
Preference for quick land use cycles						■			
Preference for 'tidy' landscapes / 'messy' perception						■			
Reduced yields and productivity losses		■							
Shortage of skilled employees		■							
Social disapproval or pressure for production efficiency							■		
Social norms and peer influence							■		
Technical limitations and workload		■							
Technology limitations									■
Top-down policy design with little farmer input				■					
Trade-offs and unintended environmental effects			■						
Trade-offs and unintended technological effects									■
Unequal distribution of benefits and financial burdens		■							
Unfair distribution of knowledge access (“élite capture”)							■		
Unsupportive or unclear legal framework				■					
Weak or absent social networks and cooperatives							■		

3.3.2 Enablers and drivers

Sustainable land use practice adoption can be driven (i.e. motivated) by a number of different factors and further enabled (i.e. made possible) by a set of other factors. 19 drivers and 20 enablers were identified from the analysed articles with the total number of 366 mentions. In this section, an overview of key drivers and enablers for sustainable land use practice adoption is provided and described.

Psychological factors have been identified as the most influential drivers of the adoption of sustainable land use practices, with nine distinct factors highlighted in the analysed literature (Table 7 and Appendix 3; see also Table 8 for a list of enablers and Appendix 4 for details of enablers). The most frequently mentioned psychological drivers are positive attitudes, social and subjective norms, motivation and trust, indicating that land user internal attitudes and perceived social expectations play a central role in shaping their behaviour when it comes to adoption. This is supported by studies showing that cultural shifts and positive societal expectations can encourage improved practices (Mills et al., 2017), while intrinsic motivation, satisfaction, and positive attitudes toward sustainability-related outcomes further strengthen adoption intentions (Karali et al., 2014; Olum et al., 2019; Barnes et al., 2019; Cammarata et al., 2024; Gemtou et al., 2024). Social norms and peer comparison also play a role (Mills et al., 2017; Gemtou et al., 2024), alongside trust in advisors, service providers, and institutions (Mills et al., 2017; Olum et al., 2019; Gemtou et al., 2024). Following closely behind are adaptation capacity, innovativeness, and openness to new practices, highlighting the importance of land user willingness and ability to experiment, learn, and adjust to new approaches. Adaptability to changing conditions, farmer innovativeness, interest in new practices, and openness to new experiences characterise this driver (Klebl et al., 2023; Gemtou et al., 2024; Rizzo et al., 2023). Confidence in one's own abilities (Cammarata et al., 2024) and good physical and mental health (Klebl et al., 2023) further strengthen this capacity.

While other psychological drivers appear less frequently, they together form a coherent overview of how beliefs, perceptions, and motivations influence the uptake of sustainable land use practices. These include user alignment of intentions with moral norms and responsibility towards future generations (Gemtou et al., 2024; Swart et al., 2023), as well as their perceived behavioural control, such as confidence, skills, and access to necessary resources (Gemtou et al., 2024; Klebl et al., 2023). The literature also highlights the importance of perceived benefits (economic, environmental or social) that strengthen land user motivation to adopt practices they perceive as advantageous (Gemtou et al., 2024). Similarly, perceived compatibility with existing farm systems and goals (Gemtou et al., 2024; Klebl et al., 2023) further supports adoption by reducing perceived complexity or conflict with current operations. Perceived ease of use, usefulness, and convenience, including ease of learning, simplifying operations, and reducing workload (Olum et al., 2019; Pierpaoli et al., 2013; Parra-Lopez et al., 2024; Gemtou et al., 2024), are important motivating factors. Support and trials can further enhance perceptions of usefulness and usability (Pierpaoli et al., 2013). Less frequently mentioned, but still relevant, are risk awareness and tolerance (Rizzo et al., 2023; Olum et al., 2019). Additionally, shifts in community norms gradually strengthen the cultural and social legitimacy of sustainable land use (Mills et al., 2017; Heller et al., 2024).

Table 7. List of identified drivers per type (in alphabetical order)

Driver / Driver type	Biophysical	Economic	Environmental	Governance	Knowledge	Psychological	Social	Structural	Technical	Mentions
Number of drivers	**1**	**2**	**3**	**1**	**1**	**9**	**2**	**-**	**1**	**-**
Adaptation capacity, innovativeness and openness to new practices						■				7
Alignment of intentions with moral norms and sense of responsibility toward future generations						■				3
Awareness of environmental, climate, and biodiversity challenges and practice benefits					■					8
Economic expectations: cost savings, market opportunities, profit and future value		■								25
Improved environmental and ecosystem outcomes			■							17
Income diversification and alternative activities		■								5
Innovations with clear relative advantage and fit									■	4
Perceived behavioural control						■				2
Perceived benefits (economic, environmental, and social) of adopting a practice						■				2
Perceived compatibility with existing farm practices and goals						■				2
Perceived ease of use and usefulness of technology or practice						■				5
Policy emphasis on productivity-environment compatibility				■						2
Positive attitudes, social and subjective norms, motivation and trust						■				15
Practice-specific agronomy benefits	■									10
Reduction in negative environmental impacts			■							6
Risk awareness and high-risk tolerance						■				2
Shift in community norms to value sustainable land use practices						■				4
Social recognition and community endorsement							■			10
Younger farmers and generational renewal							■			11

Table 8. List of identified enablers per type (in alphabetical order)

Enabler / Enabler type	Biophysical	Economic	Environmental	Governance	Knowledge	Psychological	Social	Structural	Technical	Mentions
Number of enablers	**1**	**3**	**-**	**5**	**5**	**-**	**1**	**4**	**1**	**-**
Access to and dissemination of (tailored) information and knowledge					■					18
Access to credit and investment finance		■								2
Access to data and transparent data procedures					■					3
Access to education, extension services, training, advisory and technical assistance					■					43
Collaborative networks, cooperatives and peer learning							■			26
Financial support: subsidies, incentives, grants, compensation, tax benefits		■								27
Flexible, coherent and simplified policies and administration				■						21
Full-time farmer status								■		1
Infrastructure and connectivity								■		3
Labor availability								■		2
Land ownership and farm scale								■		5
Market access, direct selling and demand development		■								5
Path dependency and existing equipment/practice base					■					8
Policies addressing attitudes, values and social norms				■						2
Practice-specific site suitability	■									11
Research evidence, trials and long-term studies					■					21
Risk mitigation strategies				■						5
Secure tenure and farmer rights				■						2
Tailored policies and support schemes				■						12
Technology availability, simplicity and compatibility									■	9

No **psychological enablers** were identified in the reviewed literature. However, the prominence and diversity of psychological drivers highlight their fundamental role as motivating forces that directly stimulate the decision to adopt sustainable land use practices. These drivers do not make adoption possible as enablers would, but instead provide the underlying reasons, incentives, and motivational "push" that lead land users toward action. Their influence lies in shaping how land users interpret risks, benefits, social expectations, and personal capabilities, making psychological drivers central to understanding why adoption occurs, even in the absence of dedicated interventions or supportive conditions that would function as enablers. Similarly, no **environmental enablers** were identified in the analysed articles.

Meanwhile, two **environmental drivers** were found to demonstrate that the promise of ecological improvement and the mitigation of environmental harm form a strong reason for motivating the adoption of sustainable land use practices. *Improved environmental and ecosystem outcomes* is the environmental driver that reflects land user recognition of benefits such as enhanced soil health, biodiversity, and ecosystem functioning. Reported improvements include biodiversity and animal welfare gains (Markiewicz-Keszycka et al., 2023) and strengthened ecosystem service provision and habitat quality (Carretero-Paulet et al., 2025; Dias de Souza et al., 2025). Adoption is also motivated by outcomes such as the restoration of degraded lands, the formation of biodiversity corridors, the use of drought-tolerant or climate-adaptive crops (Carretero-Paulet et al., 2025) and improved resource efficiency and soil–plant health (Petrovic and Csambalik, 2025). A second environmental driver, *reduction in negative environmental impacts*, encourages adoption by highlighting the potential to mitigate ecological harm. Examples include reductions in eutrophication, soil erosion, and toxicity impacts on human health and freshwater ecosystems (Dias de Souza et al., 2025), as well as lower decomposition rates of soil organic carbon (Button et al., 2022). Other motivations stem from reducing negative impacts associated with intensive production systems (Carretero-Paulet et al., 2025) and contributing to climate change mitigation and resilience (Petrovic and Csambalik, 2025).

Knowledge enablers are the most prominent enabler category in the analysed literature, emphasising the importance of increasing land user capacity to understand, evaluate and implement sustainable land use practices in order to enable adoption (Table 8 and Appendix 4). The most frequently mentioned knowledge enabler is *access to education, extension services, training, advisory services and technical assistance*. It appears as a central mechanism through which land users can gain the practical know-how and confidence needed to apply new practices effectively. This includes access to education, extension and advisory services, training programmes, personalised advice, technical assistance, and learning opportunities such as farmer open days, discussion groups, field demonstrations, and free trials (Gemtou et al., 2024; Rizzo et al., 2023; Parra-Lopez et al., 2024; Adamsone-Fiskovica and Grivins, 2024; Olum et al., 2019; Mills et al., 2017; Swart et al., 2023; Moxley et al., 2021; Pierpaoli et al., 2013; Cammarata et al., 2024; Petrovic and Csambalik, 2025; Karali et al., 2014). Strengthened advisory networks, tailored one-to-one support, and continuous agricultural education further enhance farmers' skills, confidence, and ability to adopt new practices (Mills et al., 2017; Klebl et al., 2023; Barnes et al., 2019; Masi et al., 2022).

Research evidence, trials and long-term studies provide credibility, reduce uncertainty and offer farmers concrete proof of performance under real-world conditions. Examples include agronomic trials, long-term grazing studies, chronosequence approaches, and interdisciplinary research (Button et al., 2022; Markiewicz-Keszycka et al., 2023). Verified beneficial impacts, local adaptation research, expanded research scope, and long-term funding strengthen evidence bases and help demonstrate financial, ecological, or productivity benefits (Gemtou et al., 2024; Carretero-Paulet et al., 2025; Dias de Souza et al., 2025; Swart et al., 2023). Collaborative research and inclusion of farmers in the scientific process further contribute to knowledge credibility and relevance (Parra-Lopez et al., 2024; Markiewicz-Keszycka et al., 2023).

Access to and dissemination of (tailored) information and knowledge ensures that land users receive relevant, interpretable guidance suited to their specific contexts. This is reflected in efforts to create efficient communication channels, awareness campaigns, targeted outreach strategies, and region-specific knowledge dissemination (Karali et al., 2014; Parra-Lopez et al., 2024; Barnes et al., 2019; Moxley et al., 2021; Dias de Souza et al., 2025). Also, provision of high-quality information, informational support, and timely communication that aligns with farming calendars facilitates adoption (Olum et al., 2019; Mills et al., 2017). Marketing and communication campaigns raise awareness of co-benefits and encourage wider engagement among farmers and value chain actors (Gemtou et al., 2024; Button et al., 2022).

Less frequently mentioned knowledge enablers, such as *access to data and transparent data procedures* (Barnes et al., 2019; Gemtou et al., 2024), and *path dependency and existing equipment or practice bases*, influence how feasible and accessible adoption appears, even if they are not highlighted as often. Path dependency appears through past experience, existing equipment, prior adoption of related practices, and accumulated knowledge and skills that make new adoption more feasible (Dias de Souza et al., 2025; Olum et al., 2019; Klebl et al., 2023; Barnes et al., 2019; Gemtou et al., 2024).

In contrast, only one **knowledge driver** was identified, i.e. *awareness of environmental, climate and biodiversity challenges and practice benefits*. This driver is reflected in farmers' awareness of environmental and climate challenges, environmental consciousness and experience of tangible climate impacts, as well as knowledge of biodiversity and nature conservation and their benefits (Gemtou et al., 2024; Adamsone-Fiskovica and Grivins, 2024; Klebl et al., 2023). This driver motivates adoption by increasing recognition of why sustainable practices matter, meanwhile the knowledge enablers focus on how adoption becomes possible.

Economic considerations shape both, the motivation and feasibility of adopting sustainable land use practices. The most frequently mentioned **economic driver** is *economic expectations*. It reflects farmer's anticipation of financial gains, including cost savings (Heller et al., 2024), higher income or compensation (Barnes et al., 2019; Klebl et al., 2023), favourable market opportunities (Adamsone-Fiskovica and Grivins, 2024) and increased competitiveness or productivity (Parra-Lopez et al., 2024). Farmers also respond to expectations of future value (Olum et al., 2019) and opportunities linked to high-value or differentiated products (Petrovic and Csambalik, 2025; Markiewicz-Keszycka et al., 2023). A second, less frequently mentioned driver, is *income diversification*. It emphasises the importance of stable and varied income streams. Examples include diversification into non-farming activities (Karali et al., 2014) and the pursuit of secure and diversified income sources through alternative activities (Rouet-Leduc et al., 2024).

Economic enablers primarily function by reducing financial risks and strengthening farmers' capacity to invest in new practices, yet several of them also carry a clear driving effect. The most frequently cited enabler – *financial support* – illustrates this dual role. Subsidies, incentives, grants and compensation schemes (Gemtou et al., 2024; Rizzo et al., 2023; Petrovic and Csambalik, 2025) not only enable adoption by lowering upfront costs and mitigating financial risks (Heller et al., 2024; Rouet-Leduc et al., 2024) but can also motivate adoption by making sustainable practices more economically attractive. Other forms of support, such as payment for ecosystem services (Dias de Souza et al., 2025) or carbon market incentives (Button et al., 2022; Cammarata et al., 2024), similarly blend enabling functions with motivational pull. Additional enablers, including *market access, direct selling and demand development*, supported by access to niche biodiversity-related markets (Klebl et al., 2023), local market channels (Gemtou et al., 2024), and networks for direct marketing (Rouet-Leduc et al., 2024) strengthen practice adoption feasibility by improving income opportunities. Finally, access to credit and investment finance helps unlock the capital required for upfront investments ensuring that economically motivated intentions can translate into actual adoption (Gemtou et al., 2024; Olum et al., 2019).

Governance factors play a comparatively smaller but still meaningful role in sustainable land use practice adoption, operating primarily through institutional and policy environments that either enable or constrain land user decisions. Only one **governance driver** was identified – *policy emphasis on the compatibility of productivity and the environment*. This driver was mentioned infrequently (Mills et al., 2017; Markiewicz-Keszycka et al., 2023), suggesting that, while such policy signals can motivate adoption, they are not yet a dominant source of direct motivation for land users.

The governance dimension is characterised far more strongly by **governance enablers**, which make adoption more feasible by reducing administrative burdens, mitigating risks and aligning support structures with land user needs. The most frequently mentioned enabler is *flexible, coherent, and simplified policies and administration*. It highlights the importance of reducing complexity and ensuring consistency in the policy landscape. Such flexibility can be achieved through simpler rules, reduced bureaucracy and fewer coercive restrictions (Klebl et al., 2023; Karali et al., 2014). Increased flexibility in contracts, tailored rules for extensive systems, and regulatory exemptions (Rouet-Leduc et al., 2024) were also identified as enabling mechanisms. Simplified and adaptable policy designs, e.g. less time-consuming application processes, harmonized funding rules, improved coherence across policy instruments (Karali et al., 2014; Moxley et al., 2021; Klebl et al., 2023), are suggested to ease administrative burdens.

Other governance enablers, such as *tailored policies and support schemes*, further illustrate the need for context-sensitive approaches that respond to diverse farm types, local conditions and practice-specific requirements. These include participatory policy design, collective decision-making, and the inclusion of local knowledge to ensure that measures fit real farm conditions (Mills et al., 2017; Klebl et al., 2023; Swart et al., 2023). Targeted policies that support particular groups, e.g. young farmers receiving additional benefits (Karali et al., 2014) or smallholders receiving scalability support (Parra-Lopez et al., 2024), are suggested to enhance equitable access to adoption opportunities.

Less frequently mentioned, but still relevant, are governance mechanisms that target land user underlying motivations and vulnerabilities. These include *policies that address attitudes, values, and social norms*, which aim to shift collective expectations around sustainability (Swart et al., 2023; Markiewicz-Keszycka et al., 2023). *Risk mitigation strategies*, such as insurance schemes or guarantees, lower the perceived risks of adopting unfamiliar or costly practices. The analysed articles highlight several mechanisms for reducing perceived risk, including assurances that current participation will not jeopardise future access to payments, tax benefits or other support (Moxley et al., 2021). Health insurance access (Karali et al., 2014), personalised advisory support and expert consultations (Rizzo et al., 2023), as well as broader mechanisms such as risk-sharing schemes, insurance products, and robust regulatory frameworks (Parra-Lopez et al., 2024) are suggested to reduce perceived vulnerability and risk aversion and support adoption by stabilising uncertain investment environments.

Finally, *secure tenure and farmer rights* (Karali et al., 2014; Gemtou et al., 2024) are mentioned to provide the stability needed for farmers to invest confidently in long-term sustainable land use practices and technologies. Land ownership, rather than rental arrangements, enable adoption by providing security and autonomy over management decisions (Klebl et al., 2023).

Social factors influence the adoption of sustainable land use through motivational drivers (shaping identity, recognition and values) and supportive, enabling conditions (collaborative conditions that transform motivation into practice). One key **social driver** is *social recognition and community endorsement*, reflecting farmers' responsiveness to how their practices are perceived by their peers and wider society. Studies emphasise the significance of custodianship narratives and moral framing (Mills et al., 2017), community support and social acceptability (Gemtou et al., 2024), and initiatives to enhance recognition of traditional or climate-mitigating practices (Rouet-Leduc et al., 2024; Cammarata et al., 2024). Also, feedback mechanisms (Mills et al., 2017), cultural traditions (Rouet-Leduc et al., 2024) and visibility of stewardship efforts (Mills et al., 2017) are mentioned. A second driver is *younger farmers and generational renewal*, which highlights the importance of demographic change and youth engagement. Younger farmers are often described as being more open to new technologies and practices (Petrovic and Csambalik, 2025; Gemtou et al., 2024). Succession planning (Gemtou et al., 2024) and intergenerational knowledge transfer (Swart et al., 2023) position the next generation as important agents of change.

Collaborative networks, cooperatives, and peer learning is the **social enabler** that supports adoption by creating the social infrastructure through which knowledge, support, and confidence circulate. Networks that connect farmers, researchers and advisers (Markiewicz-Keszycka et al., 2023; Rouet-Leduc et al., 2024), peer groups, farmer clusters, and community-based advisory initiatives (Mills et al., 2017; Masi et al., 2022) encourage dialogue, shared learning and collective problem solving and provide spaces for experience exchange, while cooperatives and farmer organisations offer resources, technical support, marketing opportunities, and platforms for mutual learning (Barnes et al., 2019; Gemtou et al., 2024; Olum et al., 2019).

The perceived agronomic advantages of a practice and its suitability for specific farm conditions are characterised by biophysical factors. *Practice-specific agronomic benefits* is a **biophysical driver** that motivates sustainable land use through tangible improvements in soil health, productivity and ecosystem functioning. Studies emphasise benefits such as soil carbon storage and sequestration potential, co-benefits for productivity, drought tolerance and soil stability (Button et al., 2022). Other motivating factors include the implementation of agroforestry systems that generate economic returns (Dias de Souza et al., 2025), the introduction of conservation mixes that support wildlife (Markiewicz-Keszycka et al., 2023), harvesting of cover crops for feed or bioenergy (Dias de Souza et al., 2025) and practices such as undersowing cover crops to improve germination timing (Heller et al., 2024). The sustainable land use practice adoption is motivated by agronomic benefits but ultimately depends on the practice fitting the ecological context in which it is applied. Hence, the corresponding **biophysical enabler** is *practice-specific site suitability.* This enabler supports adoption by ensuring that practices are feasible and effective under local environmental conditions. Suitability depends on factors such as soil characteristics, e.g. sandy, loamy, or silty soils (Heller et al., 2024; Button et al., 2022) and adapted crop or tree species for specific climatic conditions (Dias de Souza et al., 2025). Site suitability is also linked to the needs of mountainous or marginal areas (Klebl et al., 2023), compatibility with grassland and livestock farming systems (Klebl et al., 2023) and positive results from agricultural trials demonstrating adaptability (Carretero-Paulet et al., 2025).

The adoption of new practices and innovations is largely influenced also by technical factors, i.e. the perceived advantages and value of the innovations, as well as the practical accessibility and usability of the supporting technologies. *Innovations with a clear relative advantage and fit* was identified as a **technical driver**. Farmers are more likely to adopt practices when new solutions offer tangible improvements and align well with existing farm operations. Studies have shown that innovations that demonstrate clear relative advantages and compatibility (Rizzo et al., 2023), resource-efficient or data-driven approaches (Petrovic and Csambalik, 2025) and models that prioritise core functionality over costly performance features (Pierpaoli et al., 2013) can make sustainable options more appealing. Meanwhile, *technology availability, simplicity, and compatibility* as a **technical enabler** supports adoption by reducing practical barriers and increasing ease of use. The availability of commercially viable equipment (Button et al., 2022), contract services and shared machinery (Heller et al., 2024), and affordable, accessible technology versions (Petrovic and Csambalik, 2025) expands farmer capacity to adopt new solutions without requiring a high initial investment. Technologies are made more user-friendly through adaptations that enhance ease of learning and compatibility with farming practices (Gemtou et al., 2024) and offer simplified interfaces and operational aspects (Parra-Lopez et al., 2024).

Structural factors appear less prominently in the literature, yet they still shape the practical feasibility of adopting sustainable land use practices by defining the physical, infrastructural, and organisational conditions under which land users operate. Four **structural enablers** were identified, though these were mentioned relatively infrequently. *Farm scale* is the most frequently mentioned, reflecting that sufficient operational size enables longer-term planning and investment in sustainable practices. Larger farm size, can increase flexibility, reduce financial vulnerability, and enable investments with longer-term payback horizons. The analysed articles show that larger farms benefit from economies of scale, reduced per-unit costs, and higher investment returns (Gemtou et al., 2024). Elements such as *infrastructure and connectivity*, including internet access (Gemtou et al., 2024; Petrovic and Csambalik, 2025), irrigation and transport networks (Adamsone-Fiskovica and Grivins, 2024), facilitate smoother implementation, information exchange and market and resource access, thereby reducing logistical barriers to adoption. Similarly, *labour availability* determines whether land users have the capacity to adopt practices that require additional time, skills, or seasonal inputs (Karali et al., 2014). Finally, although it was only mentioned once, *full-time farmer status* suggests that professional commitment to farming may enhance the likelihood of engaging with new and sustainable land use practices (Gemtou et al., 2024).

No **structural drivers** were identified indicating that, unlike governance or psychological factors, structural conditions do not directly motivate adoption. Instead, they influence whether adoption is practically possible, thereby reinforcing their role as enablers rather than sources of motivation.

3.4 Conclusions

A set of factors influence a land user's decision to adopt a sustainable land use practice, including external, contextual factors, such as farm and household characteristics and social context; practice-related factors, such as knowledge, technical feasibility and economic rationality; and intrinsic factors, such as the objective and subjective characteristics of the land user. Not all factors influence adoption equally – some act as barriers, while others act as drivers or enablers. A total of 108 factors were identified across nine thematic categories.

The analysis identified 69 unique barriers to sustainable land use practice adoption across nine barrier types. Economic and psychological factors dominate adoption barriers. This indicates that sustainable land use practice adoption is affected as much by financial feasibility as by personal beliefs. Knowledge-related barriers remain prominent suggesting a gap between reliable information, advisory systems, and the practical decision-making needs of land use managers. Governance, structural, and social barriers reflect systemic constraints and show that adoption is not solely an individual choice but embedded in institutional, infrastructural, and community contexts. Technical, biophysical, and environmental barriers are less diverse and less frequently mentioned but highly context-dependent emphasising the need for tailored site-specific approaches to practice design and implementation.

The findings show that barriers to sustainable land use adoption are multifaceted and interconnected, spanning individual, organisational, and systemic dimensions. No single barrier type dominates in all contexts. Adoption is shaped by the combined effects of different factors. The findings indicate that barriers interact across categories, meaning that improving adoption at land use manager level requires coordinated systemic approach rather than isolated measures. Also, the identified 19 drivers and 20 enablers show that the adoption of sustainable land use practices depends on two fundamentally different types of influences, i.e. motivational drivers and feasibility-oriented enablers. Recognising this distinction is essential for understanding why adoption occurs, how it becomes possible and where interventions should be targeted.

Drivers represent the internal motivations, perceived benefits, and contextual signals that push land users toward sustainable practices. Findings show that adoption is primarily motivated by psychological drivers, i.e. individual attitudes, perceived norms, trust, perceived benefits, and openness to innovation. Environmental, economic, knowledge, social, biophysical, governance, and technical drivers exist but are less prevalent and more narrowly focused. They indicate that adoption decisions originate from internal evaluations of value, benefits and expectations rather than from external constraints.

Meanwhile, enablers determine whether land user motivation can be realised into practice. Enablers increase the capacity and opportunity and ensure conditions necessary for land users to act on their motivations. Knowledge enablers are most mentioned to enhance adoption through access to education, advisory services, demonstrations, research evidence, and tailored information. Economic and governance enablers are found to reduce risk, increase investment capacity, and simplify administrative or regulatory environments, while social, biophysical, technical, and structural enablers provide supportive networks, context-appropriate conditions, infrastructure and equipment.

The conceptual distinction between drivers and enablers helps explain why some land users may be willing but unable to adopt (motivated but unsupported), while others may have enabling conditions but lack motivation (supported but unconvinced). Because motivation and feasibility arise from different domains, effective interventions must address both, drivers and enablers by interventions that influence attitudes, perceived benefits, expectations while reducing cost, complexity, uncertainty.

3.5 Limitations and identified gaps

Not all land use systems / land cover types have been investigated and presented in literature. Current research on sustainable land use practices is unevenly distributed across land uses and practice types, with a strong emphasis on agriculture, croplands and grasslands, and technology- or ecosystem-based innovations. This constrains broader applicability of findings and limits the ability to generalise insights across different land use systems.

The stage of adoption was not explicitly reported in the analysed articles. While it could sometimes be inferred from context, in most cases the stage could not be determined with sufficient confidence. This limitation is further reinforced by the fact that approximately half of the analysed articles were review articles synthesising evidence from multiple studies, which did not allow identification of the specific adoption stage of a given practice or technology.

Finally, the analysis relied exclusively on academic literature. Including grey literature could have broadened the evidence base by incorporating more direct insights from land users, practitioners, extension service providers, and decision makers. Academic publications also tend to overrepresent certain regions, practices, and land use systems, thereby introducing geographical and thematic biases that have influenced the resulting identification of barriers, drivers, and enablers.

AI disclosure statement

We used OpenAI ChatGPT v5.1 to improve the writing style and check the grammar and spelling of the section. After using this tool, we reviewed and edited the content and take full responsibility for the content of this section.

4 Individuals

Second-order meta-analysis of interventions that impact behaviours with a significant effect on sustainable land use change (part of deliverable D4.4 Pathways for Meeting Sustainable Land Use Strategies In 2050)[5]

4.1 Introduction

Around the world, changes in how land is used have significant effects on the environment (Foley et al., 2005). As such, shifting toward more sustainable land use practices offers significant benefits in terms of climate change mitigation (UNFCCC, 2022) and food security (Godfray et al., 2010). Yet, land use change remains a highly complex process involving dynamic interactions of individuals, organisations, and institutions at different levels.

Individuals affect land use change mainly indirectly, playing a dual role as citizens and consumers. As citizens, individuals can, on the one hand, support pro-environmental policies that help protect and develop sustainable land use. On the other hand, due to their vested interests, they may support policies that promote urban and infrastructure development, which in turn degrade soil ecosystems (Ma et al., 2020) and undermine sustainable land use. In addition to supporting policies, individuals as citizens can also engage in activism, attempting to influence either institutional decision-making processes (Abers, 2019) or the behaviour of their fellow citizens (Ryan, 2017).

As consumers, citizens shape the market by demanding goods and services, which in turn influence changes in land use, as their production and delivery are linked to infrastructure development and changes in land use. For instance, growing demand for organic or domestic produce indirectly affects agricultural practices. Another example would be the increasing need for housing in urban areas, which may cause changes in land use through urban development. The scope of individual activities that have the potential to indirectly influence land use change is hardly limitless. This is because land use has a fundamental impact on virtually any resource or service, whether it be the production of food and textiles or the provision of housing and energy.

Although changing individual behaviour may only have a modest impact on how we exploit land-based and other ecosystems (Maniates, 2001), it can be introduced relatively quickly and at relatively low costs. As such, some argue that changing individual behaviour can buy us time to implement more profound systemic change addressing the roles of institutions and

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organisations. Changing individual behaviour can also serve as a catalyst for transforming organisational and institutional structures by leveraging their public legitimacy and support.

To effectively change individual behaviour, we need to know which interventions successfully influence behaviour or its direct precursors, such as motivation. Previous meta-analyses have revealed that many widely used behavioural interventions fail to produce meaningful changes in behaviour related to environmental protection (Osbaldiston & Schott, 2012). As such, identifying effective behavioural interventions related to land use change requires evidence from studies that examine causal effects through experimental rather than observational designs.

4.2 Objectives

The aim of this meta-analysis was to analyse the effectiveness of psychological interventions that can change individual behaviour indirectly related to land use change. Specifically, we aimed to conduct a second-order meta-analysis that would summarise causal evidence from existing meta-analyses of experimental studies that looked at the size of effects of behavioural interventions on individual behaviours with an indirect effect on land use change. As such, the current study used data from meta-analyses that specifically looked at behaviours of citizens (i.e. support for policies and activism) and behaviours of consumers (consumption of goods and services).

4.3 Method

4.3.1 Scope

We searched for meta-analytical studies that estimated the effect of behavioural interventions on individual behaviours related indirectly to land use change (outcome behaviours). We restricted outcome behaviours to the following categories:

1. general environmental behaviour (i.e. an aggregated large number of pro-environmental behaviours);
2. environmental policy support (i.e. stated willingness to support pro-environmental policies);
3. transportation;
4. energy use and conservation;
5. water use and conservation;
6. waste prevention, handling, and recycling;
7. food and produce consumption;
8. purchase of efficient durables (e.g. appliances);
9. consumption of other goods and services;
10. activism, citizen behaviour, support for NGOs;
11. home-farming decisions.

4.3.2 Search Strategy

Using our PRISMA protocol, we conducted a systematic search between October 15, 2024 and October 23, 2025 and integrated all records into a single PRISMA workflow.

We searcher several databases of academic and non-academic publications (Scopus, Web of Science, ProQuest, Open Science Pre-Prints) using the following query:

("meta-analysis" OR "meta analysis" OR metaanalysis)
AND ("environmental behaviour" OR "environmental behaviour" OR "policy support" OR transportation OR transport OR "energy use" OR "energy conservation" OR "water use" OR "water conservation" OR "waste prevention" OR recycling OR "food consumption" OR "food production" OR "purchase of efficient appliances" OR activism OR "citizen behaviour" OR "citizen behaviour" OR "support for NGOs" OR "home-farming")
AND (interventio* OR experimen* OR causa*)
AND ("pro-environmental" OR "pro environmental" OR proenvironmental)
NOT "systematic review"
NOT (animal OR animals OR "non-human" OR "non-humans" OR nonhuman OR nonhumans)

We restricted results to English-language journal articles, conference papers, correspondence, dissertations and theses, reports, working papers, and preprints published between 2014 and 2024. After removing duplicates, we screened records in two stages: (1) titles/abstracts/keywords and (2) full text, applying inclusion criteria focused on studies that (a) report a quantitative meta-analysis; (b) synthesize effects of behavioural interventions on the outcome behaviours listed above; (c) include at least some effect sizes derived from experimental evidence estimating the causal impact of interventions on outcomes; and (d) do not analyse price-based interventions. We prioritized studies that measured realised behaviours rather than intentions or attitudes.

Two reviewers independently assessed abstract-level relevance; disagreements were resolved through discussion. At this stage, we excluded studies that were not quantitative meta-analyses (N = 111), were outside the date range (N = 3), or did not concern causal effects of interventions on environmentally related behaviour (N = 5). We also incorporated 15 additional records identified through prior reviews of individual-level pro-environmental interventions known to us (Constantino et al., 2024; Green et al., 2019: Greene et al., 2023: Ixmeier et al., 2024, Karami et al., 2021; Katz et al., 2022; Krumm, 2024; Lin et al., 2022; Morren & Grinstein, 2016; Nathan et al., 2022; Nisa et al., 2019; Swart et al., 2023; Udall et al., 2021; Xia et al., 2023; Zhang et al., 2024).

This process yielded 224 publications for extraction of effect. These publications contained 551 effects out of which 494 contained all data about effects (i.e. effect size convertible to standardised effect size measure and its uncertainty given as standard error, confidence interval or estimable from sample size and/or other information).

4.3.3 Data collection process

One coder extracted the information from meta-analyses regarding experimental intervention, measures of outcome variables, whether the study was in a peer-reviewed journal, and the year of publication. One coder also extracted information about the effect sizes associated with the effect of experimental manipulation on outcome behaviours. Another coder validated the data and discussed any problems with the first coder. The coders then resolved the issues through discussion.

We would like to thank Remco S. van Beem, Anna Gašićová, Veronika Jiroutová, Michaela Lavická, Marína Murínová, and Michal Vodák for their diligent work in extracting and validating the data. Their contribution was essential for ensuring the accuracy and reliability of the dataset.

4.4 Results

The final sample consisted of 494 effect sizes from 224 publications. Out of these effect sizes, 250 were causal effects and 283 were non-causal (correlational effects). In the reminder of this text, we focused on causal effects only as these are of interest for designing interventions for behavioural change.

4.4.1 Types of intervention

Based on post-hoc coding of interventions found in the studies, we identified the following behavioural interventions used to leverage pro-environmental behaviour:

Behavioural interventions leverage different psychological drivers to encourage sustainable actions. These can be broadly categorised into information-based strategies, cognitive and emotional appeals, social influences, and structural "nudges."

1. Cognitive and Informational Strategies

These interventions focus on what the individual knows and how they justify their actions.

- **Information:** Providing factual data about a behaviour and its environmental impacts to educate the individual.
- **Justification:** Offering specific reasons **why** a behaviour is important, focusing on the rationale behind the action.
- **Instructions:** Providing procedural information or "how-to" guidance on performing a specific behaviour.
- **Prompts:** Brief visual or verbal cues placed at the point of decision-making to remind individuals of a specific activity or goal.
- **Feedback:** Providing individuals with data on their actual behaviour and its subsequent impacts, allowing for self-monitoring.

2. Internal and Psychological Drivers

These interventions target the internal state, emotions, and self-perception of the individual.

- **Affect Manipulation:** Targeting the emotions (positive or negative) that individuals experience when engaging in a specific behaviour.
- **Cognitive Dissonance:** Highlighting discrepancies between an individual's actions and their stated beliefs or values to create a "negative" psychological tension that motivates change.
- **Identity Manipulation:** Altering self-perception by highlighting past behaviours or labelling individuals (e.g. "you are a person who cares for the earth") to shift their internal identity.
- **Nature Connectedness:** Interventions designed to increase an individual's sense of emotional or psychological closeness to the natural world.

3. Social and Comparative Influences

These strategies leverage the power of peer groups and social context.

- **Social Modelling:** Providing examples of others (role models) successfully performing a behaviour for the individual to emulate.
- **Social Norms:** Highlighting the existence or prevalence of sustainable behaviours within a peer group to encourage conformity.

4. Structural and Goal-Oriented Interventions

These focus on the architecture of the choice itself or the setting of specific milestones.

- **Nudge:** Modifying "choice architecture"—the way options are presented—to make the sustainable choice the default or easier path without forbidding other options.
- **Gamification:** Integrating game-like elements (points, badges, leaderboards) to make the behaviour more engaging and enjoyable.
- **Goal Setting:** Encouraging individuals to set specific, measurable targets for their behaviour change.
- **Commitment Interventions:** Asking individuals to make a formal pledge (either privately or publicly) to carry out a specific action.

5. Integrative and Residual Categories

- **Combined Interventions:** Strategies that use a "package" of several specific interventions simultaneously (e.g. providing information + goal setting + feedback).
- **Pro-Environmental Behaviour (PEB):** An intervention where engagement in one sustainable act is used as a lever to encourage further, subsequent environmental actions.
- **Other:** A residual category for miscellaneous or niche approaches that were marginally represented in the data.

Based on the study counts, the literature on behavioural interventions shows a clear preference for traditional economic and informational strategies, while more psychologically complex or emerging approaches appear less frequently. The following summary ranks these interventions from the most frequently studied to the least.

Dominant interventions (k > 15). The most prevalent intervention in the literature is Incentives, appearing 34 times. This suggests a strong research focus on external rewards (financial or material) as a primary driver of behaviour change. This is followed by two highly common strategies: Information (k = 19k) and Nudge (k = 19k), both representing the "staples" of behavioural science—educating the public and altering choice architecture. Affect manipulation (k = 18k) and Combined interventions (k = 17k) also see significant representation, highlighting a frequent interest in emotional appeals and multi-faceted "package" approaches.

Moderately represented interventions (k = 10 to 14). A secondary tier of interventions focuses on situational cues and social context. This group includes Other (k = 13k) miscellaneous approaches, followed by Prompts (k = 12k), which provide simple reminders at the point of action. Social norms (k = 10k) also fall into this category, reflecting a consistent interest in how peer group behaviour influences the individual.

Niche and specific interventions (k = 5 to 9). Several well-known psychological techniques appear with relatively low frequency, often occurring in fewer than 10 studies: Commitment (k = 9k) and Feedback (k = 9k) are used to lock in behaviours and provide performance data.

Gamification (k = 8k), Justification (k = 8k), and Social modelling (k = 8k) are less common, suggesting they may be more difficult to implement or are specific to certain behavioural domains. Cognitive dissonance, Goal setting, and Instructions all share a frequency of 6, indicating they are utilized but not central to the mainstream body of literature sampled. Nature connectedness (k = 5k) remains a specialized area of study focused on environmental attitudes.

Emerging or rare interventions (k < 5). At the bottom of the list are Identity manipulation (k = 2k) and PEB (k = 2k). These categories are currently the least represented in the sampled literature, suggesting they are either highly specialized, difficult to manipulate experimentally, or represent emerging areas of research that have not yet achieved high study counts.

4.4.2 Types of outcome behaviours targeted with interventions

Based on post-hoc coding, we have identified the following types of behaviours targeted by behavioural interventions.

Based on post-hoc coding, we have identified the following types of behaviours targeted by behavioural interventions.

1. Comprehensive and psychological outcomes

- **General Ecological Behaviour (GEB):** A broad measure encompassing pro-environmental lifestyles, citizen behaviour, and general "green" habits.
- **Environmental Concern:** Cognitive and emotional measures focusing on attitudes and general concern for the environment rather than specific actions.
- **Environmental Policy Support:** Non-behavioural support for government or public policies aimed at environmental protection.

2. Household resource management

- **Energy Conservation:** Actions related to reducing household energy footprints, such as managing electricity and heating.
- **Waste Management:** Behaviours involving the "circular economy," including recycling, composting, and towel reuse.
- **Water Conservation:** Direct conservation efforts, such as reducing shower time or utilizing water-saving technologies.

3. Consumption and lifestyle choices

- **Sustainable Food Consumption:** Dietary shifts, including reduced meat consumption and choosing sustainable seafood.
- **Transport:** Shifts in travel behaviour, moving from car use to cycling, walking, or public transit.
- **Green Consumption & Appliances:** Purchasing energy-efficient goods, eco-products, and durable "green" appliances.

4. Specialized and advocacy

- **Environmental Activism:** High-effort engagement such as volunteering for NGOs or making financial donations.

- **Sustainability Management:** Productivity and organisational behaviours within a professional or corporate context.
- **Agriculture and Farming:** Adoption of professional farming technologies (PEATs) or personal home gardening.

Analysis of the frequency of use of these behavioural outcome categories revealed that the research is overwhelmingly focused on general lifestyle measures and household resource efficiency.

- **General Ecological Behaviour (k = 74):** By far the most frequent outcome, suggesting that many researchers prefer using broad, aggregate scales to measure intervention success.
- **Energy Conservation (k = 42):** A primary focus of behavioural economics, likely due to the ease of measuring meter data and the direct financial implications for households.
- **Waste Management (k = 41):** Nearly equal to energy, reflecting the long-standing history of "Recycle/Reuse" programs in environmental psychology.

Studies that focus on lifestyle and cognitive changes are less frequent. These studies focus on the following outcomes.

- **Sustainable Food Consumption (k = 14):** An emerging focus as the link between diet and climate change becomes more prominent in the literature.
- **Environmental Concern (k = 12):** Used when researchers are interested in shifting "hearts and minds" rather than just specific actions.
- **Water Conservation (k = 11):** While critical, it is studied nearly four times less often than energy conservation.
- **Transport (k = 9):** Surprisingly low given the high carbon impact of travel, likely due to the difficulty of shifting long-term infrastructure-dependent habits.

Some studies focused on outcomes that were rare in the literature, often lacking enough data for robust subgroup meta-analyses. These comprised the following outcome behaviours.

- **Environmental Policy Support (k = 6):** Suggests that fewer interventions are designed to influence political or systemic change.
- **Environmental Activism (k = 1) and Green Consumption (k = 1):** These high-impact behaviours are rarely the primary dependent variable in this specific dataset.
- **Home Farming, Sustainable Agriculture, and Other (k = 0):** None of the studies that focused on causal impacts of interventions targeted these behaviours.

4.4.3 Effectiveness of Behavioural Interventions

Using random-effects meta-analysis, we analysed first the effects of interventions on outcome variables. These effects are expressed in standardised effect metrics (Cohen's d) but also in how many people needs to be treated to change behaviour of one (Number Needed to Treat, NNT). Details of results are given in Table 9 below.

The meta-analysis reveals that the most powerful interventions are primarily cognitive and goal-oriented in nature. **Justification** (d = 0.598) and **Cognitive Dissonance** (d = 0.590) emerged as the strongest drivers of change, yielding the largest effect sizes in the dataset. These were followed closely by the broad category of **Psychological Correlates** (d = 0.576), which provided a highly stable and significant predictor of behavioural outcomes. Other interventions that surpassed the 0.50 threshold, indicating a robust impact, included **Goal Setting** (d = 0.528) and **Prompts** (d = 0.524), suggesting that providing clear rationales and immediate cues for action are among the most effective strategies for shifting behaviour.

Moderate effect sizes were observed for a variety of traditional behavioural strategies, including **Feedback** (d = 0.476), **Social Modelling** (d = 0.463), and **Nature Connectedness** (d = 0.433). Interestingly, many of the most common interventions in the literature produced more modest impacts; for example, **Nudges** (d = 0.370), **Social Norms** (d = 0.323), and **Incentives** (d = 0.302) all fell within a lower-moderate range. At the bottom of the spectrum, **Information** (d = 0.278) and **Combined** interventions (d = 0.250) showed significantly smaller effects, while **Pro-Environmental Behaviour (PEB)** as an intervention itself demonstrated a negligible effect (d = -0.020). This gradient highlights a clear distinction between highly potent cognitive tools and more traditional, lower-impact informational or incentive-based approaches.

Table 9. Effect sizes of each intervention type

Intervention	Estimate (d)	95% CI Lower	95% CI Upper	NNT
Justification	0.598	0.230	0.965	3.1
Cognitive Dissonance	0.590	0.143	1.038	3.1
Psychological Correlates	0.576	0.522	0.630	3.2
Goal Setting	0.528	0.121	0.936	3.4
Prompts	0.524	0.264	0.785	3.5
Feedback	0.476	0.092	0.860	3.8
Social Modeling	0.463	0.105	0.821	3.9
Nature Connectedness	0.433	0.195	0.671	4.2
Instructions	0.406	-0.011	0.823	4.4
Affect Manipulation	0.391	0.208	0.574	4.6
Nudge	0.370	0.185	0.556	4.8
Social Norms	0.323	0.149	0.498	5.5
Incentives	0.302	0.153	0.451	5.9
Other	0.298	0.168	0.428	6.0
Commitment	0.289	-0.012	0.591	6.2
Gamification	0.287	0.021	0.553	6.2

Information	0.278	0.135	0.420	6.4
Identity Manipulation	0.258	-0.174	0.690	6.9
Combined	0.250	0.080	0.420	7.1
PEB	-0.020	-0.543	0.503	N/A

Next, we looked at what outcome behaviours are most amenable to behavioural change using mixed-effect meta-analysis. Details of results are given in Table 10. The subgroup analysis of dependent variables reveals that interventions are most effective when targeting specific, high-impact resource behaviours rather than broad attitudes. **Transport** interventions showed the highest potency (d = 0.787, k = 9), achieving a highly efficient Number Needed to Treat (NNT) of 2.4. This was followed by **Water Conservation** (d = 0.595, k = 11), which also demonstrated a robust and statistically significant effect. These results suggest that behaviours associated with clear, direct actions—such as shifting commuting habits or reducing water usage—are the most responsive to behavioural change strategies.

Conversely, the data indicates a significant drop in effectiveness when interventions target more generalized or abstract outcomes. While **General Ecological Behaviour (GEB)** was the most frequently studied outcome (k = 74), it yielded a relatively small effect size (d = 0.265) and a much higher NNT of 6.7. Household staples like **Energy Conservation** and **Waste Management** showed consistent, moderate effects (d ≈0.40). Notably, interventions failed to produce statistically significant changes in **Environmental Policy Support** and **Environmental Concern** (p > .05). This suggests that current behavioural interventions are successful at modifying specific physical actions but struggle to significantly shift broader political attitudes or psychological concern for the environment.

Table 10. Effect sizes found for each type of outcome behaviour

Outcome Behaviour	Estimate (d)	95% CI Lower	95% CI Upper	NNT
Transport	0.787	0.470	1.104	2.4
Green Consumption	0.690	-0.386	1.766	2.7
Water Conservation	0.595	0.304	0.886	3.1
Energy Conservation	0.400	0.287	0.512	4.5
Waste Management	0.390	0.265	0.516	4.6
Environmental Activism	0.360	-1.544	2.264	5.0
General Ecological Behaviour	0.265	0.194	0.337	6.7
Sustainable Food Consumption	0.252	0.079	0.425	7.1
Environmental Policy Support	0.183	-0.054	0.419	9.7
Environmental Concern	0.111	-0.069	0.291	16.0

4.4.4 Conclusions

The following discussion section synthesizes the results into practical and policy-oriented frameworks, focusing on the strategic shift required to improve the efficacy of behavioural change initiatives.

The findings indicate a clear hierarchy in the efficacy of behavioural tools, suggesting that the "Information-Incentive" paradigm—while dominant in literature and practice—is less efficient than cognitive-based strategies. The high performance of justification and cognitive dissonance suggests that individuals are more likely to sustain behavioural change when they internalize a logical rationale or experience a psychological need for consistency between their beliefs and actions.

For practitioners, this implies a shift in communication strategy: rather than simply providing educational data (information) or external rewards (incentives), programs should design environments that prompt self-reflection and personal accountability. Practical applications might include "commitment-and-consistency" loops where participants are invited to align their identity with their environmental goals, thereby leveraging internal motivation rather than external pressure.

Behavioural Specificity vs. Attitudinal Shifts

A critical distinction emerged between the malleability of specific behaviours and the relative rigidity of broader environmental concern and policy support. The high success rates in transport and water conservation suggest that behavioural interventions are most effective when applied to discrete, repetitive, and tangible actions. In contrast, the lack of significant impact on environmental concern and policy support indicates that brief behavioural interventions are generally insufficient to shift deeply held political attitudes or systemic worldviews.

Stakeholders should therefore treat behavioural interventions as tools for immediate action rather than as primary drivers of long-term ideological change. To bridge this gap, policy designs might consider a "bottom-up" approach, where successful behavioural shifts in transport or energy use are used as evidence to build public confidence in larger, systemic policy changes over time.

Implications for Policymakers and Stakeholders

Resource Allocation: Policymakers should prioritize funding for interventions that utilize goal setting, prompts, and justification. Given their lower Number Needed to Treat (NNT), these methods offer a higher return on investment per participant compared to traditional awareness campaigns.

Infrastructure over Information: The success of transport-related interventions suggests that when behavioural cues are paired with specific actions, significant change is possible. Stakeholders should integrate behavioural prompts directly into infrastructure (e.g. at transit hubs or point-of-use water fixtures) to maximize the "choice architecture" effect.

Addressing the Policy Gap: Since interventions aimed at individuals rarely translate into increased support for environmental legislation, a distinct and separate strategy is required for advocacy and policy-level engagement. Behavioural change at the household level should be viewed as a complement to, rather than a substitute for, structural and regulatory reform.

5 Summary and integration of the three analyses

5.1 Purpose of the task

The overarching objective of Task 4.4 *Identifying measures to create change* is to identify the most powerful interventions and social innovations that can change how policy, planning, governance systems, organisations and individuals (as consumers and citizens with indirect impact on land use) operate and behave and how to make these more pro-environmental and sustainable. While a great amount of research has been conducted on interventions and their effectiveness, the results show that the effectiveness often depends on context and the other interventions that are implemented in combination.

5.2 Method

To integrate the results of WP4 *Transformation Pathways for Land Use Strategies* tasks and activities, the chosen approach is the Theory of Change (ToC) approach (Leisher et al., 2024, Morales Munoz et al., 2023). ToC is an approach or tool, presented in the form of a schematic presentation with a narrative, that is used in project management to develop impact pathways supporting project design, and to evaluate progress towards project long-term goals. Underlying assumptions are made explicit. The pathways start with interventions, then move from outputs (products, goods or services that result from an intervention) via outcomes (behavioural and other changes) to impacts (the goal: the desired larger societal changes) in impact pathways (Leisher et al., 2024). Note that the ToC developed here was not used in the Practice Cases or for further monitoring and evaluation purposes.

Drawing on project outputs from WP2 *Historical Land Use Change*, WP3 *Future sustainable land use strategies* and WP4 *Transformation Pathways for Land Use Strategies* and applying this approach allows us to identify which points in the system (e.g. citizens, landowners, planners, etc.) need to be targeted, and what kinds of values and governance approaches can be utilised to create sustainable land use change. Using the ToC, we identified three broad starting domains from which pathways to impacts were identified: landowners and managers, consumers and citizens, and finally, the government (at multiple levels) providing the enabling environment. For visual representation of this framework, see Figure 4. These domains interact to achieve the desired outputs, outcomes and impacts, and were borrowed from the Energizing Development project (https://endev.info/).

5.3 Data

Different inputs were synthesised to generate the ToC.

Short-term actions and outputs were identified from the results of Tasks 4.4 *Identifying measures to create change*, i.e. the three meta-analyses of governments, land user managers, and behavioural responses of citizens and consumers, as presented in the preceding chapters of this Deliverable. We also used Deliverable 4.*1 Intervention points for creating land use policy and decision-making change* to identify short- and medium-term outputs and outcomes, as well as intervention points (IP). Deliverable 3.2 *Report on the Policy Drivers of Land Use Change* was consulted for the long-term impacts and policy drivers, and its causal loop diagram was used to describe some of the pathways to impact elaborated here. Deliverable 3.4 *Descriptive land use scenarios to 2050 for European regions* was used primarily to identify interventions, outputs and short-term outcomes in the enabling environment. The resulting 'Theory of Change' diagram was validated by emailing with the task leads of WP4 *Transformation Pathways for Land Use Strategies*.

5.4 Results

Impacts and long-term outcomes

The PLUS Change project broadly focuses on climate change mitigation and adaptation, biodiversity conservation and human well-being. In the ToC these have been termed carbon neutrality (following EU policy goal), soil protection and restoration (another specific EU policy goal), biodiversity conservation, a broader category of socio-economic benefits and (more specifically) health benefits and quality of life. These are highly interdependent and can be found at the top of the ToC as the long-term overarching impacts.

In order to achieve these, an assumption expressed in the ToC is that all policies integrate social, economic, climate and biodiversity goals. This policy integration at all levels of policy-making is necessary for achieving the sectoral targets as well as the overall impacts.

Under the long-term outcomes, the EU targets for 2030 are included for the domains land use, energy, transport, urban environment and waste. These domains were identified in Deliverable 3.2 *Report on the Policy Drivers of Land Use Change* as relevant for land use strategies towards the desired impacts. These outcomes are first specified at a more generic level, followed by the quantified targets per policy domain.

Short- and medium-term

The short and medium-term outcomes, outputs and interventions have been split into three areas: the supply side where land use managers implement land uses to supply (public and commercial) goods and services (darker green, left), the enabling environment created by multi-level governance (lighter green, middle), and the citizen and consumer side which creates demand for goods and services provided by sustainable land use systems (grey, right). These three areas are interdependent: demand and supply interact, and the enabling environment creates the conditions under which both suppliers and consumers act, whereas citizens engage with governments to shape public policy.

Supply side

For the land managers (supply side), the main barriers, as identified in the section on Land use managers, included factors related to individual land managers (perceptions, attitudes, knowledge), economic conditions, institutional and social/network conditions, and site-specific factors. The main *interventions* are divided into four groups that each provide enablers to address these barriers: knowledge (e.g. training, knowledge transfer, accessible tailored information), economic enablers (e.g. financial support (subsidies, grants, tax release), income diversification options), governance enablers (e.g. tailored policies, simplified administrative and regulatory environment), and social enablers (e.g. community cooperation, peer exchange, succession planning).

Assuming that land use managers engage with these interventions, the expected *outputs* of these interventions include increased knowledge on sustainable land use (SLU) practices and greater self-efficacy, the development of diversified business models and reduced risks for SLU managers, the greater flexibility for SLU practice implementation and participatory design of tailored policies, and the establishment of stronger professional networks and peer-learning platforms for land use managers, and youth engagement into SLU practices.

Assuming that these outputs provide sufficient motivation for land use managers to switch from conventional to sustainable practices, the expected short- and medium-term outcomes include the adoption of ecosystem-based, technology-based, and socio-economic innovations in land use. The latter for instance includes local food system practices, explored in more detail in Deliverable 4.3 *Report on the impacts of behaviour changes on biodiversity, climate and well-being indicators*.

These outcomes are expected to result in the long-term outcomes for 2030, primarily those related to habitat, carbon, biodiversity, forest, ecology, and sustainable agricultural production systems (darker green outlined long-term outcomes).

Enabling environment

This area contains the activities at multiple levels of government, in order to facilitate both citizens and consumers as well as land managers to contribute to achieving the desired impacts.

The governance analysis presented in this deliverable points towards three key activities that seem to have been relatively more effective in achieving sustainable land use: setting clear and credible policy goals for climate and biodiversity (intervention) should help to create strategies tailored to local conditions and over time in implementation and enforcement, and establishing monitoring, evaluation and learning (MEL) and verification systems for long-term monitoring, learning and verification strategies (outputs). These interventions also need to be supported by a set of policies, i.e. policy mixes, including those that support land managers (supply side), and instigate change among consumers/citizens.

These outputs, assuming that they are implemented across different policy domains and governments at multiple levels have the capacity to do so, support key intervention points (IPs, see Deliverable 3.1 *2D representations of Possible Landscapes in the Practice Cases*) related to adaptive land use policy that responds to dynamic changes, cross-sectoral and cross-scale policy integration, and strong policy implementation.

A separate pathway to impact connects citizens, civil society organisations (CSOs) and non-governmental organisations (NGOs) to the enabling environment, by engaging these in policy-making, thereby creating stronger multi-actor participation in policy-making and increasing the democratic quality of governance. This pathway to impact is related to the justice considerations, emphasised in PLUS Change, aiming to generate socio-economic and well-being benefits for all, including marginalised or commonly excluded groups.

Demand side: Citizens and consumers

Based on the meta-analysis of individual behavioural change presented in this deliverable, three types of interventions addressing individual people in their role as citizen or consumer are identified: based on messaging (e.g. calling upon social norms, providing information about behaviour and related implications, or prompts), activities (e.g. commitments), or cost-based interventions (e.g. nudges or incentives).

Interventions with the most direct link to land use, and found to be relatively effective, include those that address behaviour related to food consumption and processing, and transport. Calling upon social norms or nudging is likely to be most effective. Assuming that consumers respond to these interventions, they are expected to change their behaviour such that demand for sustainably produced food as well as public or sustainable modes of transport increases. If enacted together with the support on the supply side to encourage land managers to adopt SLU practices, these behavioural changes can lead to the creation of sustainable and local food systems which are more likely to support the societal impacts compared to current intensive land use and food systems.

Interventions on other areas of individual behaviour with environmental impacts, including the use of energy and water, purchasing durable and non-food items, and the management of waste, can also lead to changes in demand. These in turn influence energy, housing and recycling systems, which is likely to have repercussions on land use. This can either be through land use conversion towards biofuels, housing or solar PV parks, or land fragmentation due to infrastructure, but also energy use reduction.

Finally, interventions can also encourage people to take active part in democratic processes by increasing awareness and empowering people to get politically involved. This can increase public support for SLU and wider environmental policies and increase public support for NGO and CSO activities. Such activism and support are likely to create synergies with efforts towards multi-actor participation in the enabling environment, and ultimately safeguard the provision of socio-economic benefits and well-being for all.

5.5 Discussion

It is recognised that many of the targets for 2030 are coming close, and there is little time between the short- and medium-term outcomes and the 2030 targeted outcomes. Switching from intensive to (sustainable) extensive forms of agricultural land use has been shown to take years. At the same time, it must be acknowledged that such transitions are rolling out in many EU countries.

The ToC does not specify interventions, outputs or short and medium-term outcomes for sectors that are included under the long-term outcomes, including transport, housing, waste management, and energy. This is a possible bias, but this choice is to an extent defensible as the food system has a dominant role in affecting land use change and climate change globally, even if it may not reflect local land change drivers. Furthermore, the ToC does not consider wider supply chain actors that can facilitate transformative change in the food system, such as financial institutions, and value chain actors (food processors, wholesale, convenience stores, etc).

This ToC could be developed and fine-tuned further by a clearer understanding of the underlying assumptions between outputs and outcomes, and between outcomes and impacts. The complexity of land use change makes it difficult to compare pathways to impact and identify the most effective or appropriate interventions points. Nonetheless, the ToC offers a high-level, schematic overview that can be tailored to local contexts, and in that process identify action points for different stakeholders.

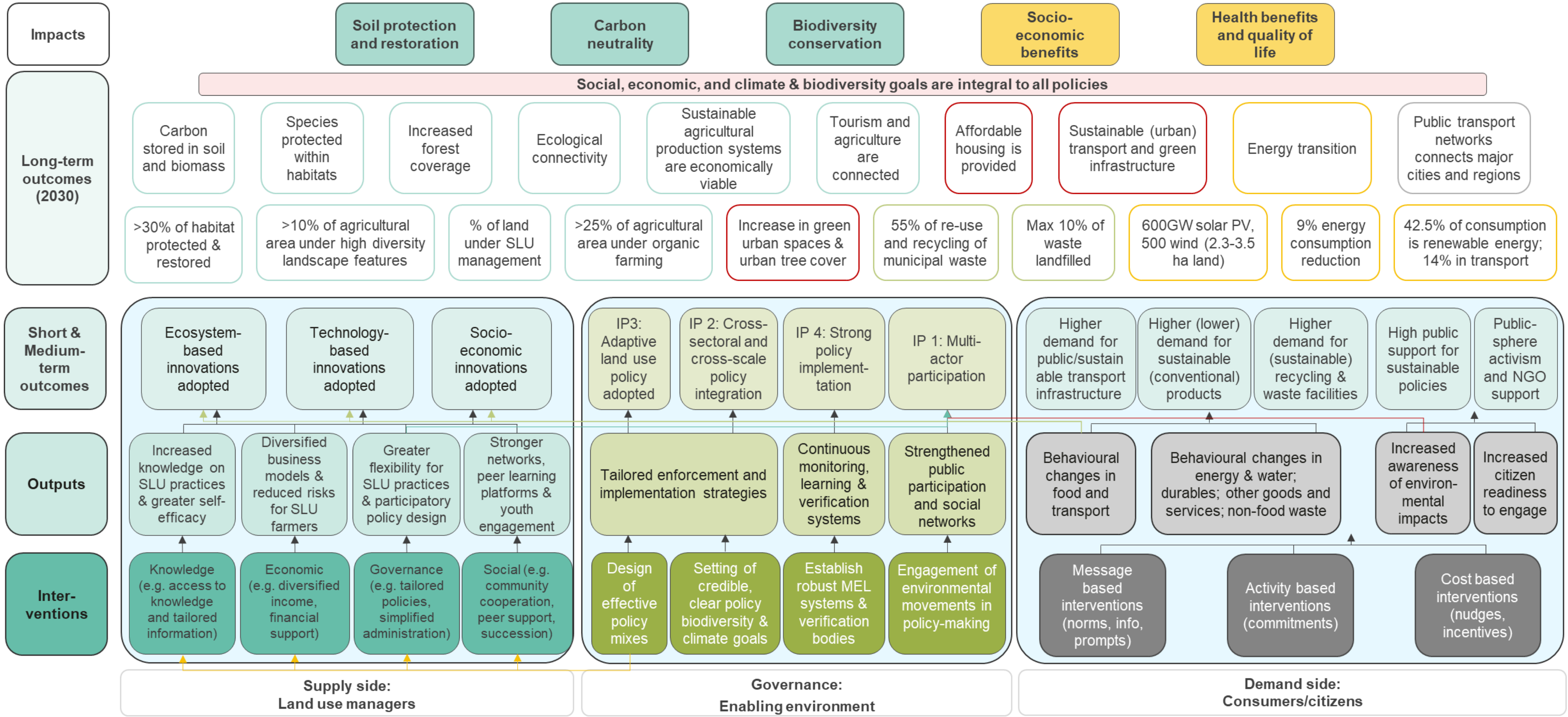

Figure 4. Integration of the three layers of analysis using the framework of the Theory of Change

6 Conclusions: Strategies for transformation

This deliverable integrates the diverse outputs of the plus change project to establish a robust empirical foundation for the upcoming activities in WP5. By synthesising meta-analytical evidence across the three domains of governance, land management, and individual behaviour, the project has transitioned from identifying isolated drivers to mapping the specific configurations required for landscape-scale transformation. The resulting theory of change (toc) illustrates the dynamic pathways through which policy mixes, steward identity, and consumer demand converge to achieve the overarching goals of climate neutrality, biodiversity restoration, and enhanced human well-being.

A primary finding of this synthesis is the necessity of shifting from an 'information-incentive' model to a 'cognitive-structural' framework, as data and financial rewards alone are often insufficient to sustain long-term change. Effective interventions must leverage internalised identity by aligning sustainable practices with personal values, such as professional stewardship, which proves more durable than external pressure. Furthermore, prioritising choice architecture ensures sustainable land use becomes the default through behavioural cues embedded in the physical and regulatory environment, while addressing the policy-action gap ensures that localised behavioural shifts are complemented by distinct strategies for structural and legislative reform.

To move from theory to practice, these findings must be applied across governance scales, from EU policy mixes that integrate socio-economic goals to regional infrastructure-based cues that foster social proof. The project's practice cases serve as the frontline for testing these pathways in WP5, focusing on identity-based engagement and peer-learning to lower cultural resistance to systemic change. By testing configurations of knowledge, economic, and social enablers, WP5 will develop adaptive pathways that bridge short-term behavioural shifts to long-term 2050 targets, ensuring that transformations are biophysically viable, socially just, and democratically supported.

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Appendix

Appendix 1. An overview of the cases included in the meta-analysis

Paper	Country	Intervention	Instrument	Outcome	Key factor
Haensel et al., 2023	DE	Anticipated CAP reforms (2009 Health Check, 2013 CAP Reform); Changes in IACS eligibility and AES access rules; Farmers reacting to expected restrictions	Spatial planning/Regulatory + Economic	Pre-emptive conversion of grassland due to anticipation CAP reforms	-Lack of interim safeguards -Credible policy signals
Haensel et al., 2023	DE	5% permanent grassland quota rule (CAP 2003 cross-compliance), binding in Bavaria as of 2014; CAP Greening (2013 reform), implemented in Germany in 2015	Spatial planning/Regulatory + Economic	Stabilized permanent grassland conversion at 20–30 km^2/year	No factor identified
Haensel et al., 2023	DE	Designation of protected areas: SACs (legal from 2006), SPAs (legal from 2016), National Parks (dates unspecified), Biosphere Reserves (core/buffer zones)	Spatial planning /Regulatory	Near-zero permanent grassland conversion in National Parks and early SACs	-Early designation timing -Strong enforcement in some zones
Haensel et al., 2023	DE	Peatland Protection Ordinance, Erosion Zones Ordinance, Water Protection Zones (2003 onwards); Legal designation without enforcement	Spatial planning + Economic	Continued permanent grassland loss despite nominal protection	No binding restrictions and thus no enforcement mechanisms
Haensel et al., 2023	DE	Voluntary AES programs: KLIP and Vertragsnaturschutzprogramm; Incentive-based payments conditional on long-term enrollment	Spatial planning + Economic (incentives)	Moderate permanent grassland retention in long-term AES areas	-Long AES contracts (≥8 years) -Non-overlap with legal protections
Haensel et al., 2023	DE	Bavarian referendum (2019); Amendment of Bavarian Nature Conservation Act introducing statewide PG conversion ban	Spatial planning /Regulatory (incentives referenced)	Record low permanent grassland conversion (~12 km^2 in 2020)	-Strong legal clarity -Broad civic legitimacy
Brenner et al., 2024	AT	Soft Urban Renewal Schemes	Spatial planning + Partnership	Limiting urban densification and urban sprawl	-Combined with Greenbelt policy -Fragmented landownerships -

					Increasing demand for living working spaces
Brenner et al., 2024	AT	Protection of Vienna ́s Greenbelt: 1. Green space zoning; 2. Natura 2000 directive; 3. Biosphere Park directive	Spatial planning	Preservation of Vienna's Greenbelt to curb urban sprawl	-Explicit regulations -Long-term implementation -Inner-city outmigration from dense urban areas towards greener, less dense areas
Brenner et al., 2024	AT	Local government grants single-family housing building permits; Allotment Garden Act Amendment	Others (removal of restriction) + Spatial planning	Entrenched urban sprawl through housing construction in urban green spaces	No factor identified
Book et al., 2010	DK	Ørestad Model with the Ørestad Development Corporation and Finger Plan	Institutional rearrangement + Spatial planning + Partnership	Development of new districts in Copenhagen linked by a new metro connection to central Copenhagen (environmental sustainability outcomes remain uncertain, with mixed positive and negative impacts).	No factor identified
Cengiz et al., 2019	TR	Economic-growth- oriented development policies: urban growth driven mainly by municipal-level liberalization, narrowing of the public sector, squatter amnesties, and forest and agricultural land conversion	Spatial planning	Urban sprawl and growth, as well as deforestation	No factor identified
Cengiz et al., 2019	TR	Neoliberal urbanization resulting in a centralized construction economy dominated by symbolic mega-projects, supported by institutions such as Mass Housing Administration (TOKI)	Spatial planning	Urban sprawl and growth as well as deforestation.	No factor identified
Xue et al., 2011	DK	The Finger Plan (1947), especially the 2007 revision promoting residential and office development close to stations	Spatial planning	Densification in center areas and development in outer areas located close to rail/metro stations	No factor identified

Guerra et al., 2016	PT	Wheat campaign (1928), Agrarian reform (1975-1982), Agricultural transitory measures (1980-1986)	Spatial planning + Economic	Mixed pattern of croplands increase and decrease; permanent pastures increased towards the end of the timeframe	No factor identified
Guerra et al., 2016	PT	Specific Programme for Portuguese agriculture (PEDAP, 1986-1992), Common Agricultural Policy (1992-1996)	Economic	Afforestation of marginal areas, alongside grazing and production intensification on favorable land	No factor identified
Guerra et al., 2016	PT	Common Agricultural Policy (2000–2013): Agenda 2000 and "second pillar" providing payment for environmental and cultural measures	Economic	Afforestation of marginal areas, alongside grazing and production intensification on favorable land	Budget constraints for "second pillar" (environmental & social measures)
Dumitrașcu et al., 2024	RO	Operational Programme 'Increase of Economic Competitiveness' (2007–2014) and Green certificates (until 2014)	Economic	Rapid expansion of renewable electricity capacity; Attraction of large-scale private investment; Over-incentivisation and market distortion	- Level of financial support (overcompensation) - Investor expectations and policy credibility
Dumitrașcu et al., 2024	RO	Reduction of Green Certificates to 50% after 2014 (2015-2020)	Economic	Sharp slowdown in renewable energy investment; Increased regulatory uncertainty; Market consolidation; Short-term cost containment	-Regulatory instability and retroactive policy change -Policy uncertainty
Pinto-Correia & Azeda, 2017	PT	Long-term effect of CAP and mangement. practice on Montado ecosystem and farmer's livelihood	Regulatory + Economic	Persistence with gradual degradation; Stabilisation with subsidy dependence	-Path dependency - Management practices -Subsidy reliance
Lehtonen & Rankinen, 2015	FI	Finnish agri-environmental support scheme in Yläneenjoki region	Economic	Limited observable land-use change; Improved environmental awareness; Partial environmental improvements; yet the scheme did not fully achieve its ecological goals at catchment scale.	Farmer attitudes and voluntary uptake

Raum, 2020	UK	Forestry Act 1919 & 1951	Spatial planning/Regulatory + Institutional rearrangement	Creation of Forestry Commission; expansion of forest cover; institutional base for forestry	-Generosity of the Green Certificate scheme -Stability and predictability of the support framework
Raum, 2020	UK	Wildlife & Countryside Act 1981/85, Broadleaved Policy 1985, Biodiversity Action Plan 1994, UK Forest Standard (1998)	Spatial planning/Regulatory + Institutional rearrangement + Economic	Shift toward biodiversity/conservation, sustainable forest management, habitat protection	-Retroactive policy change -Regulatory uncertainty
Monteleone et al., 2018	IT	Pre 2003 CAP	Regulatory + Economic	Intensification; Pressure on land and ecosystems; Reduced land-use diversity; Income stabilisation through production	Production linkage
Monteleone et al., 2018	IT	Post 2003 CAP	Regulatory + Economic	Land use extensification and stabilisation; Reduced production intensity; Improved environmental performance (limited); Income support decoupled from production	-Degree of decoupling -Cross-compliance implementation -Path dependency

Appendix 2. Most common barriers and their relevant adoption factor groups (in the order of prevalent barrier types)

Type of barrier	Common theme of barriers	Barriers extracted from articles	Factor group	Frequency[6]
Knowledge	Lack of knowledge, skills, and technical capacity	Insufficient knowledge (Adamsone-Fiskovica and Grivins, 2024), Lack of ability (skills / knowledge) despite willingness (Mills et al., 2017), Lack of education (Barnes et al., 2019; Olum et al., 2019; Rizzo et al., 2023), Lack of knowledge (Markiewicz-Keszycka et al., 2023; Dias de Souza et al., 2025), Lack of knowledge, advice, or technical capacity (Klebl et al., 2023), Lack of skills (Gemtou et al., 2024), Lack of skills and competencies among non-adopters (Pierpaoli et al., 2013), Lack of skills, interest, and communication (Masi et al., 2022), Lack of sufficient knowledge of best-practice integration (Petrovic and Csambalik, 2025), Limited equipment and skills (Moxley et al., 2021), Limited knowledge (Cammarata et al., 2024), Need for particular agro-ecosystem knowledge and understanding (Heller et al., 2024), Need to develop new skills and knowledge (Petrovic and Csambalik, 2025)	Factors intrinsic to the individual: Objective individual characteristics	17
Knowledge	Limited evidence base and insufficient research on long-term environmental and productivity effects	Insufficient study duration to detect long-term effects (Markiewicz-Keszycka et al., 2023), Lack of evidence (Markiewicz-Keszycka et al., 2023), Lack of research on product quality, biodiversity, animal health (Markiewicz-Keszycka et al., 2023), Lack of research, education, and knowledge infrastructure (Gemtou et al., 2024), Limited evidence base (especially field scale) (Button et al., 2022), Limited evidence for long-term C storage (Button et al., 2022), Limited evidence on biochar impacts and sequestration potential (Button et al., 2022), Limited evidence; long-term impacts unknown (Button et al., 2022), Limited research (few teams; narrow scope) (Markiewicz-Keszycka et al., 2023), Limited research on organic farming impacts (Markiewicz-Keszycka et al., 2023), Limited research on productivity, biodiversity, GHG emissions (Markiewicz-Keszycka et al., 2023), Perceived absence of solid evidence on positive impact (Gemtou et al., 2024)	Factors related to the practice: Knowledge	12

[6] Number of mentions of the common barrier theme in analysed articles. Only barriers with at least four mentions included.

Knowledge	Lack of awareness or shared understanding of environmental challenges, policy frameworks, and benefits	Lack of awareness / popularity of VCM (Cammarata et al., 2024), Lack of awareness of environmental challenges / CSA benefits (Gemtou et al., 2024), Lack of awareness of policy framework (Moxley et al., 2021), Lack of common understanding towards the impact of addition of C-rich wastes to C stock (Button et al., 2022), Lack of environmental awareness (Karali et al., 2014), Limited awareness and valorisation of local wild species (Carretero-Paulet et al., 2025), Limited knowledge of farmers' motivations / values (Markiewicz-Keszycka et al., 2023),	Factors intrinsic to the individual: Subjective individual characteristics (perceptions)	7
Knowledge; Structural	Lack of expert advice or technical support	Expert knowledge disconnected from practitioners (Rouet-Leduc et al., 2024), Isolation: poor access to education / support (Rouet-Leduc et al., 2024), Lack of expert advice (Adamsone-Fiskovica and Grivins, 2024), Lack of extension / advisory services (Gemtou et al., 2024), Lack of training and technical support (Barnes et al., 2019), Low digital skills and advisory support (Parra-Lopez et al., 2024), Poor advice support (Rizzo et al., 2023), Poor technical support (Masi et al., 2022)	Factors related to the practice: Knowledge	8
Knowledge; Structural	Lack of access to reliable, understandable information	Complex information difficult to understand or evaluate (Karali et al., 2014), Information from untrustworthy sources (Klebl et al., 2023), Lack of access to information (Olum et al., 2019), Lack of access to reliable, understandable information (Klebl et al., 2023), Limited access to timely, reliable, unbiased information (Gemtou et al., 2024)	Factors related to the practice: Knowledge	5
Knowledge; Psychological	Lack of trust in information sources, technologies, or scientific evidence	Difficulty translating science into practice; confusion, mistrust (Karali et al., 2014), Lack of trust in experimental farm studies (Barnes et al., 2019), Lack of trust in sources (media, government, peers) (Gemtou et al., 2024), Lack of trust in technologies (Gemtou et al., 2024),	Factors related to the practice: Knowledge	4
Economic	Economic and financial constraints and uncertainty of returns	Economic constraints to engage in sustainable grazing (Rouet-Leduc et al., 2024), High opportunity costs (Klebl et al., 2023), High perceived cost or low perceived benefit (Gemtou et al., 2024), Increase in direct and indirect costs (Adamsone-Fiskovica and Grivins, 2024), Increase in production costs from adopting technologies (Pierpaoli et al., 2013), Lack of perceived economic benefits (Adamsone-Fiskovica and Grivins, 2024), Low cost-effectiveness (Karali et al., 2014), Short-term financial constraints (Parra-Lopez et al., 2024), Uncertainty of economic return (Barnes et al., 2019), Uncertainty over ongoing costs and support (Moxley et al., 2021), Uncertainty regarding ROI (Cammarata et al., 2024)	Factors related to the practice: Economic rationality	11

Economic	High initial investment costs	High cost of entry (Barnes et al., 2019), High cost/price of innovation (Olum et al., 2019), High equipment costs (Heller et al., 2024), High initial investment costs (esp. small farms) (Petrovic and Csambalik, 2025; Masi et al., 2022), High transaction and implementation costs (Klebl et al., 2023), High upfront capital costs (Moxley et al., 2021)	Factors related to the practice: Economic rationality	8
Economic; Biophysical	Reduced yields and productivity losses	Increased root allocation reduces aboveground harvest (Button et al., 2022), Insufficient profitability (Parra-Lopez et al., 2024), Decline in cultivation of promising species (Carretero-Paulet et al., 2025), Lack of immediate economic returns (Parra-Lopez et al., 2024), Low risk of yield reduction can lower income (Dias de Souza et al., 2025), Reduction in main crop yields (Dias de Souza et al., 2025), Yield reductions and higher financial risks (Heller et al., 2024)	External/ contextual factors: Farm characteristics (Quantity of farm production)	7
Economic	Unequal distribution of benefits and financial burdens	Cover crops add costs but no immediate return (Dias de Souza et al., 2025), Distribution of expenses (Karali et al., 2014), High operating costs and stagnant support (Rouet-Leduc et al., 2024), No economic gains from buffer zones (Dias de Souza et al., 2025), Payments not compensating intangible benefits (Markiewicz-Keszycka et al., 2023)	Factors related to the practice: Economic rationality	5
Economic; Knowledge	Limited market development and awareness for new or alternative crops	Lack of market for conservation agriculture products (Heller et al., 2024), Lack of market outlets (organic/specialty) (Markiewicz-Keszycka et al., 2023), Lack of marketing channels (Rouet-Leduc et al., 2024), Limited market development for new crops (Carretero-Paulet et al., 2025), Low market demand or fear of low prices (Gemtou et al., 2024),	Factors related to the practice: Economic rationality	5
Economic; Structural	Distance to markets, suppliers, and services	Distance to/from markets, services, suppliers (Masi et al., 2022; Petrovic and Csambalik, 2025), Instability/lack of market or access (Adamsone-Fiskovica and Grivins, 2024), Lack of market access (Gemtou et al., 2024)	Factors related to the practice: Economic rationality	4
Psychological	Older age and experience-based reliance of farmers contributing to resistance to change	Older age of farmer or land use manager (Barnes et al., 2019; Gemtou et al., 2024; Klebl et al., 2023; Mills et al., 2017; Petrovic and Csambalik, 2025; Adamsone-Fiskovica and Grivins, 2024; Olum et al., 2019), Older farmers' reliance on experience (Masi et al., 2022), Health issues (Karali et al., 2014)	Factors intrinsic to the individual: Objective individual characteristics (age)	9

Psychological; Technical	Perceived complexity or low usefulness of technologies and innovations	High innovation aversion / low perceived control (Rizzo et al., 2023), Lack of perceived relative advantage or compatibility of innovation (Rizzo et al., 2023), Perceived complexity of new technologies (Masi et al., 2022), Perceived complexity or incompatibility of PA tools (Pierpaoli et al., 2013), Perceived low usefulness or difficulty of use (Pierpaoli et al., 2013), Perceived usefulness and ease of use (Swart et al., 2023), Perception of lost productivity (Mills et al., 2017)	Factors intrinsic to the individual: Subjective individual characteristics (perceptions)	7
Psychological	Perceived risks / risk aversion	Associating practice with risks (e.g. higher pest occurrence) (Klebl et al., 2023), Fear of adverse effects due to lack of information (Dias de Souza et al., 2025), Perceived risks / risk aversion (Olum et al., 2019), Residual risk or uncertainty (Parra-Lopez et al., 2024), Risk aversion (Gemtou et al., 2024; Karali et al., 2014)	Factors intrinsic to the individual: Subjective individual characteristics (perceptions)	6
Psychological	Established productivist mindsets and resistance to change	Conflicting motives (Gemtou et al., 2024), Deep-seated productivist beliefs (Mills et al., 2017), Desire for recognition/status based on productivity (Mills et al., 2017), Established mindsets & work styles (Swart et al., 2023), Over-reliance on financial incentives ("tick-box" attitude) (Mills et al., 2017)	Factors intrinsic to the individual: Subjective individual characteristics (personality)	5
Psychological	Negative attitudes towards sustainable practices	Negative attitudes (Gemtou et al., 2024), Negative attitudes linked with reduced productivity (Markiewicz-Keszycka et al., 2023), Negative attitudes towards sustainable practices (Swart et al., 2023), Resistance due to differing knowledge and attitudes (Moxley et al., 2021)	Factors intrinsic to the individual: Subjective individual characteristics (attitudes)	4
Psychological	Low self-efficacy, reinvention capacity or confidence	Lack of adaptation or reinvention capacity (Rizzo et al., 2023), Lack of sense of ownership and stewardship (Swart et al., 2023), Lack of supportive subjective norms (Swart et al., 2023), Low self-efficacy or confidence (Klebl et al., 2023),	Factors intrinsic to the individual: Subjective individual characteristics (behavioural control / self-efficacy)	4
Governance	Unsupportive or unclear legal framework	CAP not covering certain land-users / counterproductive for grazing (Rouet-Leduc et al., 2024), Conflicting government messages (productivity vs stewardship) (Mills et al., 2017), Difficult-to-follow carbon codes (SMEs) (Cammarata et al., 2024), Legislative barriers surrounding addition of C-rich wastes (Button et al., 2022), Poor	External/ contextual factors: Factors related to institutions	11

		institutional support (Masi et al., 2022), Productivist policies (focus on economic over motivational factors) (Swart et al., 2023), Rules that do not match local conditions (Karali et al., 2014), Unclear future prospects of herbicides / risk of bans (Heller et al., 2024), Unclear guidelines (Klebl et al., 2023), Unequal subsidies favouring large/intensive farms (Rouet-Leduc et al., 2024), Unsupportive legal framework (lack of compensation, long-term vision) (Gemtou et al., 2024)		
Governance	High bureaucratic burden and inflexible administrative procedures in support schemes	Administrative bureaucracy / inflexibility (Moxley et al., 2021), Bureaucratic application process (Karali et al., 2014), Bureaucratic burdens and inflexible procedures (Klebl et al., 2023), Complex interactions between public/private funding schemes (Moxley et al., 2021), Continuous and strict follow-up controls (added cost, loss of autonomy) (Karali et al., 2014), High bureaucratic burden, control, and time for certification schemes (Gemtou et al., 2024), Out-of-touch schemes with excessive administrative burden/sanctions (Rouet-Leduc et al., 2024), Rigid/bureaucratic financial support schemes (Gemtou et al., 2024)	External/ contextual factors: Factors related to institutions	8
Structural; Economic	Farm size limitations	Farm size (too small) and land quality (too good) as barriers to forestry (Markiewicz-Keszycka et al., 2023), Farm size limitations (small or large) (Rizzo et al., 2023), Limited financial, human, and technical resources (Cammarata et al., 2024), Limited resources and capacity to invest (small farms) (Parra-Lopez et al., 2024), Scale-dependence of implementation (Markiewicz-Keszycka et al., 2023), Small farm size (Barnes et al., 2019; Gemtou et al., 2024), Small farm size limiting tech adoption (Parra-Lopez et al., 2024), Small farms in marginal rural areas (Masi et al., 2022)	External/contextual factors: Farm characteristics (land endowment)	9
Structural; Economic	High labour demands and shortage of skilled workforce	Fixed labour supply making management inflexible (Karali et al., 2014), Lack of human resources (aging, rural exodus) (Rouet-Leduc et al., 2024), Need for hired labour (Karali et al., 2014), Physically demanding nature of grazing work (Rouet-Leduc et al., 2024), Unfavourable working conditions (Rizzo et al., 2023)	Factors related to the practice: Economic rationality	5
Structural	Lack of infrastructure (internet, irrigation, roads, communication)	Lack of infrastructure (internet, irrigation, roads, communication) (Gemtou et al., 2024), Lack of irrigation (Adamsone-Fiskovica and Grivins, 2024), Lack of stable & reliable internet (Petrovic and Csambalik, 2025), Unavailability of internet and computers (Karali et al., 2014)	External/contextual factors: Access to infrastructure	4
Social	Weak or absent social networks and cooperatives	Isolation and lack of networks (Mills et al., 2017), Lack of comparison with peers (Rizzo et al., 2023), Lack of supportive rural/family networks (Rouet-Leduc et al., 2024), Limited peer exchange / social learning (Gemtou et al., 2024), Low social pressure (Cammarata et al., 2024), Need for large social uptake to reverse declines	External/ contextual: Social context (engagement in social networks)	8

		(Markiewicz-Keszycka et al., 2023), Weak or absent social networks (Klebl et al., 2023), Weak social networks and cooperatives (Karali et al., 2014),		
Social; Psychological	Social norms and peer influence	Heterogeneity in farmer values, willingness, and capacity (Mills et al., 2017), Low peer adoption of other precision ag technologies (Barnes et al., 2019), Peer acceptance / others' opinions (Heller et al., 2024), Perceived social norms (Swart et al., 2023),	External/contextual factors: Social context (social influence)	4
Social; Psychological	Absence of successor and youth disinterest in farming	Absence of successor (Karali et al., 2014), Difficulties of farming discouraging youth (Karali et al., 2014), Lack of succession (Gemtou et al., 2024), Youth disinterest in farming (Rouet-Leduc et al., 2024)	External/contextual factors: Farm characteristics (pathways)	4
Technical	Complexity or incompatibility of innovations and technologies	Complex or incompatible technologies (Gemtou et al., 2024), Complexity of innovations (Rizzo et al., 2023), Impractical tagging/microchipping for free-ranging animals (Rouet-Leduc et al., 2024), Lack of practicality (Button et al., 2022), Need for adaptation to local environmental conditions for exotic crops (Carretero-Paulet et al., 2025), One-size-fits-all solutions unlikely (due to local variation) (Markiewicz-Keszycka et al., 2023), Technical complexity (Parra-Lopez et al., 2024)	Factors related to the practice: Technical feasibility	7
Technical	Technology limitations	Lack of genomic resources for breeding wild species (Carretero-Paulet et al., 2025), Limited access to appropriate technology (Petrovic and Csambalik, 2025), Limited application to organic soils: rapid SOM loss from drained peatlands (Button et al., 2022), Unavailability of adequate machinery (Heller et al., 2024), Uneven maturing of crops (Adamsone-Fiskovica and Grivins, 2024)	Factors related to the practice: Technical feasibility	5
Technical	Trade-offs and unintended technological effects	Cover crops can return as weed on the following year (Dias de Souza et al., 2025), Impossibility to incorporate manure without ploughing (Heller et al., 2024), Long establishment time before cattle reintroduced (Markiewicz-Keszycka et al., 2023), Mechanization reducing manual job opportunities (Rouet-Leduc et al., 2024)	Factors related to the practice: Technical feasibility	4
Environmental	Trade-offs and unintended environmental effects	Buffer zone design influences ecosystem services (Dias de Souza et al., 2025), C input from deep ploughing outweighed by C lost to respiration (Button et al., 2022), Increased flooding risk due to raised water table (Button et al., 2022), Increased risk of N_2O and CH_4 emissions under raised water table (Button et al., 2022), Risk of impaired root growth and reduced yields due to raised water table (Button et al., 2022), Soil instability caused by raised water table (Button et al., 2022), Trade-off: benefits for birds but increases CO_2 release from soil (Markiewicz-Keszycka et al.,	Factors related to the practice: Technical feasibility	8

		2023), Unintended negative environmental outcomes (decline of certain bird species) (Markiewicz-Keszycka et al., 2023)		
Biophysical	Climatic limitations	Cold and wet climatic conditions / short growing season (Heller et al., 2024), Inappropriate climatic conditions (e.g. water availability is not sufficient) (Karali et al., 2014), Inappropriate climatic conditions (temperature, water availability) (Heller et al., 2024), Input-intensive staple crops poorly adapted to climate change (Carretero-Paulet et al., 2025), Low temperatures reduce tree growth and buffer zone effectiveness (Dias de Souza et al., 2025), Short growing season with limited sunlight (Dias de Souza et al., 2025), Unsuitable conditions or climate (Markiewicz-Keszycka et al., 2023)	External/contextual factors: Farm characteristics (biophysical characteristics)	8
Biophysical	Biophysical constraints and features of farms	Biophysical constraints on farm (Mills et al., 2017), Biophysical features of farms (e.g. topography, soil quality) (Karali et al., 2014), Clayey soils (Heller et al., 2024), Limited application in some soil conditions (Button et al., 2022)	External/contextual factors: Farm characteristics (biophysical characteristics)	4

Appendix 3. Most common drivers and their relevant adoption factor groups (in alphabetic order of driver type)

Type of driver	Common theme of driver	Drivers extracted from articles	Factor group	Frequency[7]
Biophysical	Practice-specific agronomy benefits	Biochar stability and persistence in soil (Button et al., 2022), Breeding deep-rooted crops to promote harvestable biomass (Button et al., 2022), Co-benefits for productivity, drought tolerance, and soil stability (Button et al., 2022), Harvesting cover crops for animal feed or bioenergy purposes (Dias de Souza et al., 2025), Implementation of agroforestry (e.g. fruit trees) as buffer zones providing economic returns (Dias de Souza et al., 2025), Inclusion of conservation mixes (seed-rich plants/crops) to provide winter food (Markiewicz-Keszycka et al., 2023), Increased carbon sequestration and mitigation potential (Dias de Souza et al., 2025), Increased soil carbon storage (Button et al., 2022), Potential for soil organic carbon sequestration (Button et al., 2022), Undersowing cover crops into established main crops to advance germination dates (Heller et al., 2024)	External/contextual factors: Farm characteristics (biophysical characteristics)	10
Economic	Economic expectations: cost savings, market opportunities, profit and future value	Anticipated economic benefits (Adamsone-Fiskovica and Grivins, 2024), Cost savings from adoption (reduced labour and fuel costs) (Heller et al., 2024), Economic potential and market demand for orphan crops (Carretero-Paulet et al., 2025), Enhanced business image and innovation potential (Cammarata et al., 2024), Expanding market opportunities (Rouet-Leduc et al., 2024), Expectation of future value (Olum et al., 2019), Favourable market conditions (Adamsone-Fiskovica and Grivins, 2024), High value of produce or products (Petrovic and Csambalik, 2025), Higher financial compensation (Klebl et al., 2023), Higher income (Barnes et al., 2019; Olum et al., 2019), Higher yields offset implementation costs (Button et al., 2022), Improved competitiveness (Parra-Lopez et al., 2024), Increased productivity (Parra-Lopez et al., 2024), Long-term yield benefits (Dias de Souza et al., 2025), Opportunities to sell sustainable products (e.g. subsidies for farm shops) (Rouet-Leduc et al., 2024),	Factors intrinsic to the individual: Subjective individual characteristics (perceptions) / Factors related to the practice: Economic rationality	25

[7] Number of mentions of the common driver theme in analysed articles. Only drivers with at least four mentions included.

		Positive consumer perception and market benefits from biodiversity-based products (Markiewicz-Keszycka et al., 2023), Potential to generate additional income from by-products (Markiewicz-Keszycka et al., 2023), Production of higher-quality or additional products (Klebl et al., 2023), Profit orientation and long-term management perspective (Parra-Lopez et al., 2024), Profit prospects (Adamsone-Fiskovica and Grivins, 2024), Profitability and economic advantage (Parra-Lopez et al., 2024), Reduced input use (e.g. fertilizers, pesticides, energy) (Klebl et al., 2023), Reduced uncertainty about economic returns (Barnes et al., 2019), Rising industrial demand and proven environmental benefits (e.g. carbon capture, reforestation) (Carretero-Paulet et al., 2025).		
Economic	Income diversification and alternative activities	Diversification into non-farming activities (Karali et al., 2014), Diversified or multiple income sources (Adamsone-Fiskovica and Grivins, 2024), Farm diversification strategy (Karali et al., 2014), Income diversification (Rouet-Leduc et al., 2024), Secure and diversified income sources (Karali et al., 2014)	Factors related to the practice: Economic rationality	5
Environmental	Improved environmental and ecosystem outcomes	Artificial drainage enhances carbon storage in mineral soils (Button et al., 2022), Careful management (e.g. consideration of the C/N ratio of cover crop residues) (Button et al., 2022), Climate change adaptation and resilience capacity (Carretero-Paulet et al., 2025), Deep ploughing increases long-term soil organic matter (Button et al., 2022), Diversification with drought- and heat-tolerant orphan crops (Carretero-Paulet et al., 2025), Ecosystem service provision and biodiversity benefits (Carretero-Paulet et al., 2025), Enhanced resource efficiency and soil–plant health (Petrovic and Csambalik, 2025), Environmental adaptability (e.g. drought resistance) (Olum et al., 2019), Improved biodiversity and animal welfare outcomes (Markiewicz-Keszycka et al., 2023), Improved environmental and ecosystem outcomes (e.g. water quality, biodiversity, soil formation) (Markiewicz-Keszycka et al., 2023), Improved habitat quality and biodiversity (Dias de Souza et al., 2025), Integration of perennial and open-field systems to create biodiversity corridors (Carretero-Paulet et al., 2025), Potential for biodiversity enhancement and improved animal/environmental health (Markiewicz-Keszycka et al., 2023), Potential for biodiversity enhancement and reduced environmental impacts (Markiewicz-Keszycka et al., 2023), Raising the water table in organic soils to re-establish anoxic conditions and prevent SOM loss (Button et al., 2022), Reintroduction and domestication of orphan and wild crops with high adaptive and nutritional potential (Carretero-Paulet et al., 2025), Restoration of degraded lands and ecosystems (Carretero-Paulet et al., 2025)	External/contextual factors: Farm characteristics (biophysical characteristics)	17

Environmental	Reduction in negative environmental impacts	Mitigating climate change and enhancing resilience (Petrovic and Csambalik, 2025), Reduced decomposition rates of Fe-associated soil organic carbon (Button et al., 2022), Reduced toxicity impacts on human health and freshwater ecosystems (Dias de Souza et al., 2025), Reduction in eutrophication impacts (Dias de Souza et al., 2025), Reduction in soil erosion (Dias de Souza et al., 2025), Reduction of environmental impacts in intensive production systems (Carretero-Paulet et al., 2025)	External/contextual factors: Farm characteristics (biophysical characteristics)	6
Knowledge	Awareness of environmental, climate, and biodiversity challenges and practice benefits	Awareness of environmental and climate challenges and CSA benefits (Gemtou et al., 2024), Environmental awareness (Adamsone-Fiskovica and Grivins, 2024), Environmental consciousness (awareness of impact of agricultural activities) (Gemtou et al., 2024), Experience of tangible climate change impacts (Adamsone-Fiskovica and Grivins, 2024), Knowledge of biodiversity and nature conservation (Klebl et al., 2023), Pro-environmental attitudes and awareness of biodiversity and landscape value (Klebl et al., 2023), Raising public awareness about climate challenges and practical responses (Gemtou et al., 2024), Understanding of biodiversity benefits (e.g. pest control) (Klebl et al., 2023)	Factors related to the practice: Knowledge	8
Psychological	Positive attitudes, social and subjective norms, motivation and trust	Cultural shifts and positive societal expectations encouraging improved practices (Mills et al., 2017), Encouraging internal motivation, peer comparison, and social norms (Mills et al., 2017), Intrinsic motivation for environmental protection (Karali et al., 2014), Knowledge about farmers' attitudes, perceived outcomes, and beliefs in their own capabilities (Swart et al., 2023), Long-term trust-building with known advisors (Mills et al., 2017), Positive attitude (Olum et al., 2019), Positive attitude toward payback (Barnes et al., 2019), Positive attitude toward voluntary carbon markets (VCM) (Cammarata et al., 2024), Positive attitudes toward sustainable practices (Gemtou et al., 2024), Satisfaction (Olum et al., 2019), Shifting cultural norms to include environmental performance as part of being a "good farmer" (Klebl et al., 2023), Stronger environmental vision (greater prioritization of sustainability) (Rizzo et al., 2023), Subjective norms and social approval (Gemtou et al., 2024), Trust in information sources and institutions (Gemtou et al., 2024), Trust in service providers (Olum et al., 2019)	Factors intrinsic to the individual: Subjective individual characteristics (attitudes)	15
Psychological	Adaptation capacity, innovativeness and openness to new practices	Adaptability to changing conditions (Klebl et al., 2023), Confidence in one's abilities (perceived behavioural control) (Cammarata et al., 2024), Farmer innovativeness and openness to new practices (Gemtou et al., 2024), Farmers' capacity for adaptation and reinvention (Rizzo et al., 2023), Good physical and mental health of the farmer (Klebl et al., 2023), Interest in new practices (Gemtou et al., 2024), Openness to new experiences (Gemtou et al., 2024)	Factors intrinsic to the individual: Subjective individual characteristics (behavioural	7

			intention and motivation)	
Psychological	Perceived ease of use and usefulness of technology or practice	Ease and convenience of farm management (Parra-Lopez et al., 2024),Ease of use, usefulness, amount of improvement in technology (Olum et al., 2019),Enhancing perceived usefulness (PU) and ease of use (PEU) through support and trials (Pierpaoli et al., 2013),Perceived ease of use (user-friendliness, ease of learning) (Gemtou et al., 2024),Perceived usefulness (enhancing farm productivity, reducing workload, simplifying operations) (Gemtou et al., 2024)	Factors intrinsic to the individual: Subjective individual characteristics (perceptions)	5
Psychological	Shift in community norms to value sustainable land use practices	Climate change adaptation and mitigation aligning with farmers' and public ideals (Heller et al., 2024), Framing environmental management as an integral component of long-term sustainable food production (Mills et al., 2017), Internalization of environmental management activities into the farming habitus (Mills et al., 2017), Shift in community norms toward valuing environmental management (Mills et al., 2017),	External/contextual factors: Social context (social influence)	4
Social	Younger farmers and generational renewal	Availability of succession planning (Gemtou et al., 2024), Generational shift in values (Mills et al., 2017), Moral obligation and concern for future generations (Klebl et al., 2023), Working with the next generation of farmers, linking improved business management with higher levels of environmental management (Mills et al., 2017), Younger age and openness to new practices (Gemtou et al., 2024), Younger age of farmer (Barnes et al., 2019; Klebl et al., 2023), Younger farmers and large farms as early adopters (Petrovic and Csambalik, 2025), Younger farmers' openness to adopting new technology (Petrovic and Csambalik, 2025), Younger generations and intergenerational knowledge transfer (Swart et al., 2023)	External/contextual factors: Farm characteristics (pathways)	11
Social	Social recognition and community endorsement	Custodianship narratives and moral framing of environmental responsibility (Mills et al., 2017), Enhancement of public acceptance and recognition of traditional practices as cultural assets (Rouet-Leduc et al., 2024), Improved feedback and recognition mechanisms (Mills et al., 2017), Improving social acceptability through narrative change (Rouet-Leduc et al., 2024), Official recognition for climate-mitigating farms (Cammarata et al., 2024), Social acceptability and community support (Gemtou et al., 2024), Social recognition for BFFM (Klebl et al., 2023), Strengthening cultural traditions and reframing grazing identity to attract youth (Rouet-Leduc et al., 2024), Strengthening social endorsement of VCM through community engagement and promotion of	External/contextual factors: Social context (social influence)	10

		successful case studies (Cammarata et al., 2024), Supportive social environments (Rouet-Leduc et al., 2024)		
Technical	Innovations with clear relative advantage and fit	Focus on core functionality rather than performance to reduce costs (disruptive innovation model) (Pierpaoli et al., 2013), Innovations designed to demonstrate clear relative advantages and farm compatibility (Rizzo et al., 2023), Open innovation fostering a balance between productivity and sustainability (Rizzo et al., 2023), Resource-efficient and data-driven farming (Petrovic and Csambalik, 2025)	Factors related to the practice: Technical feasibility	4

Appendix 4. Most common enablers and their relevant adoption factor groups (in alphabetic order of enabler type)

Type of enabler	**Common theme of enabler**	**Enablers extracted from articles**	**Factor group**	**Frequency**[8]
Biophysical	Practice-specific site suitability	Appropriate tree density for ruminant production in temperate oceanic climates (Markiewicz-Keszycka et al., 2023), Farmers in mountainous, marginal, or less-favored areas (Klebl et al., 2023), Grassland and livestock farming systems (Klebl et al., 2023), Integration of buffer zones with other agricultural practices that address specific cropland issues (Dias de Souza et al., 2025), Presence of sandy or loamy soils (Heller et al., 2024), Selection of cover crops adapted to the Norwegian climate (Dias de Souza et al., 2025), Selection of tree species adapted to the Norwegian climate over conventional crops (Dias de Souza et al., 2025), Successful agricultural trials and demonstrated adaptability (Carretero-Paulet et al., 2025), Suitability of subsoils for long-term carbon sequestration (Button et al., 2022), Suitable soil type and location (e.g. Silty and Duplex soils) (Button et al., 2022), Use of site-adapted cover crop varieties and mixtures with higher climatic tolerance (Heller et al., 2024)	External/contextual factors: Farm characteristics (biophysical characteristics)	11
Economic	Financial support: subsidies, incentives, grants, compensation, tax benefits	Availability of financial or policy incentives (Olum et al., 2019), Certification schemes ensuring product quality, providing subsidies, higher selling prices, or indirect publicity (Gemtou et al., 2024), Compatibility of payment levels with site conditions and farm specialization (Klebl et al., 2023), Continued subsidies (Karali et al., 2014), Economic incentives (Rizzo et al., 2023), Economic support through subsidies (Rouet-Leduc et al., 2024), Financial aid to cover labour costs during peak periods (Karali et al., 2014), Financial flexibility framework (flexible financing options, grants, and subsidies) (Parra-Lopez et al., 2024), Financial incentives (e.g. through carbon markets or agri-environment schemes) (Button et al., 2022), Financial support covering costs and adapting to price increases (Rouet-Leduc et al., 2024), Financial support for acquiring new machinery (Petrovic and Csambalik, 2025), Government financial assistance (subsidies, tax	Factors related to the practice: Economic rationality	27

[8] Number of mentions of the common enabler theme in analysed articles. Only enablers with at least four mentions included.

		reductions, compensation schemes) (Gemtou et al., 2024), Higher and tailored compensation covering opportunity costs (Klebl et al., 2023), Incentives and soft loans (Olum et al., 2019), Incentives for environmental improvement (Parra-Lopez et al., 2024), Income support payments (Barnes et al., 2019), Increased financial support from public and private R&D sectors (Markiewicz-Keszycka et al., 2023), Other forms of economic support for grazing management, including national nature protection funds or private foundations (Rouet-Leduc et al., 2024), Payment for ecosystem services (Dias de Souza et al., 2025), Profitability acceleration schemes (subsidies, tax credits, low-interest loans, grants) (Parra-Lopez et al., 2024), Providing incentives such as reduced participation costs in carbon registries or fair valuation of carbon credits (Cammarata et al., 2024), Subsidies (Adamsone-Fiskovica and Grivins, 2024), Subsidies and other financial incentives to cover additional costs or compensate for yield reductions and risks (Heller et al., 2024), Subsidies compensating economic losses (Dias de Souza et al., 2025), Subsidies, favourable financing, and tax incentives reducing initial costs and mitigating financial risks (Rizzo et al., 2023), Subsidies, grants, or low-interest loans (Petrovic and Csambalik, 2025), Targeted subsidies (Gemtou et al., 2024),		
Economic	Market access, direct selling and demand development	Access to markets (for biodiversity-related niche products) (Klebl et al., 2023), Alternative channels for direct selling (Gemtou et al., 2024), Easy access to markets (Gemtou et al., 2024), Networks for direct marketing (Rouet-Leduc et al., 2024), Short supply chains and local market access (Gemtou et al., 2024),	Factors related to the practice: Economic rationality	5
Governance	Flexible, coherent and simplified policies and administration	AECM options allowing greater flexibility in implementation (Rouet-Leduc et al., 2024), Clear, coherent, and stable policy guidelines with simplified rules (Klebl et al., 2023), Enablement interventions (Rouet-Leduc et al., 2024), Environmental restructuring interventions (Rouet-Leduc et al., 2024), Fewer coercive controls and restrictions (Karali et al., 2014), Flexibility, regulatory exemptions, or tailored rules for extensive systems (Rouet-Leduc et al., 2024), Flexible, less bureaucratic subsidies and certification schemes (Gemtou et al., 2024), Improved integration of funding schemes, flexible timelines, and harmonized additionality rules (Moxley et al., 2021), Improvement in coherence of CAP instruments (Rouet-Leduc et al., 2024), Increased flexibility in contracts and management (Klebl et al., 2023), Integration of policies across sectors (e.g. ensuring water availability) (Karali et al., 2014), Making VCM accessible to small and medium-sized farms (Cammarata et al., 2024), Options providing greater flexibility (Rouet-Leduc et al., 2024), Policymakers ensuring flexibility of AES when designing new schemes (Markiewicz-Keszycka et al., 2023), Reducing the regulatory burden on sustainable practices (Rouet-Leduc et al., 2024), Simpler and less time-consuming application processes (Karali et al., 2014), Simplified and adaptable policy design with	External/ contextual factors: Factors related to institutions	21

		locally tailored, flexible contracts (Klebl et al., 2023), Simplified and more flexible administrative arrangements (Moxley et al., 2021), Tailored policy design accounting for heterogeneity in farmer characteristics and contexts (Gemtou et al., 2024), Tailoring policy instruments to farmers' needs (Karali et al., 2014), Well-thought-out and targeted policies supported by flexible policy design and long-term governmental vision (Gemtou et al., 2024)		
Governance	Tailored policies and support schemes	Adaptation strategies suited to farm scale and associated advantages (Rizzo et al., 2023), Collective and participatory decision-making (Gemtou et al., 2024), Ensuring access to necessary resources and support (Cammarata et al., 2024), Increased scheme flexibility and inclusion of local knowledge (Mills et al., 2017), Participation and co-design in policymaking (Klebl et al., 2023), Participatory policy design (Swart et al., 2023), Prioritizing development of practical solutions for farming based on circular economy (Markiewicz-Keszycka et al., 2023), Providing young farmers with additional benefits (e.g. access to land, financial incentives, lower taxes) (Karali et al., 2014), Scalability support programmes (subsidies for smallholders, infrastructure investment, public–private partnerships, tailored digital solutions) (Parra-Lopez et al., 2024), Supportive legal and policy framework (Gemtou et al., 2024), Targeted engagement with young, organic, well-educated farmers with off-farm income and recent farming experience (Markiewicz-Keszycka et al., 2023), Targeted policies and support (Gemtou et al., 2024),	External/ contextual factors: Factors related to institutions	12
Governance	Risk mitigation strategies	Assurances that current participation does not reduce future eligibility for payments or tax benefits (Moxley et al., 2021), Ensuring access to health insurance (Karali et al., 2014), Expert consultants providing personalized advice to mitigate risk perceptions (Rizzo et al., 2023), Reduced risk aversion and availability of risk management tools (Gemtou et al., 2024), Risk mitigation strategies (risk-sharing mechanisms, insurance schemes, guarantees, robust regulatory frameworks) (Parra-Lopez et al., 2024)	External/ contextual factors: Factors related to institutions	5
Governance	Secure tenure and farmer rights	Farm ownership or secure tenancy arrangements (Gemtou et al., 2024), Land owned (Olum et al., 2019), Land ownership (not leased) (Klebl et al., 2023), Secure farmer rights within robust policy frameworks (Karali et al., 2014)	External/contextual factors: Farm characteristics (tenure security)	4
Knowledge	Access to education, extension services, training, advisory and technical assistance	Access to education, extension services, training, formal education programs, and farm demonstrations (Gemtou et al., 2024), Access to expert consultants providing personalized advice (Rizzo et al., 2023), Access to extension and advisory services (Parra-Lopez et al., 2024; Adamsone-Fiskovica and Grivins, 2024), Accessible and relevant research, education, and knowledge (Gemtou et al., 2024), Advisory services sharing knowledge and experiences (Rizzo et al., 2023; Heller et al., 2024), Continuous agricultural education (Rizzo et al., 2023), Education level (Olum et al., 2019), Education	Factors related to the practice: Knowledge	43

		providing in-depth information about specific practices and their benefits (Rizzo et al., 2023), Education, extension services, training programs, and advisory support (Gemtou et al., 2024), Education, financial support, and context-specific advice on enhancing environmental value (Mills et al., 2017), Education, training, or exchange with other farmers, and information provision interventions (Swart et al., 2023), Efforts to increase capacity, notably through subsidized advice, investment, and training (Moxley et al., 2021), Evaluability through pilot or demonstration projects (Parra-Lopez et al., 2024), Extension services and technical assistance helping farmers understand the potential of the VCM (Cammarata et al., 2024), Farmer open days, discussion groups, and media initiatives (Gemtou et al., 2024), Higher education level associated with adoption (Gemtou et al., 2024; Petrovic and Csambalik, 2025), In-field demonstrations, free trials, and support services to build skills and confidence (Pierpaoli et al., 2013), Influence of biodiversity or environmental advisors (Klebl et al., 2023), Investment in learning (Barnes et al., 2019), Knowledge of voluntary carbon markets (VCM) (Cammarata et al., 2024), Making farmers aware of and trained in the real potential of innovation (Masi et al., 2022),Ongoing education and access to the latest innovations and technologies (Rizzo et al., 2023), Personalized advice and practical guidance (Klebl et al., 2023), Programme to strengthen advisory networks (increased funding and training for extension services, expanded networks of professional advisors and knowledge brokers) (Parra-Lopez et al., 2024), Providing necessary skills, improved knowledge transfer, and accessible advisory services (Masi et al., 2022), Providing training (Masi et al., 2022), Public and private extension services offering information and technical assistance (Swart et al., 2023), Skills development initiatives (comprehensive training programmes, workshops, and continuous learning opportunities) (Parra-Lopez et al., 2024), Skills, knowledge, education, and prior experience (Klebl et al., 2023), Social learning through observing or directly experiencing other farmers' CSA use (Gemtou et al., 2024), Strengthened advisory services (Gemtou et al., 2024), Tailored technical support (Rizzo et al., 2023), Tailored, one-to-one advisory approaches (Mills et al., 2017), Targeted communication and educational initiatives (Cammarata et al., 2024), Technical assistance and hands-on support (Rizzo et al., 2023), Training (Barnes et al., 2019), Training events, exhibitions, and one-to-one communication mechanisms (Karali et al., 2014), Training programs, workshops, and field demonstrations (Petrovic and Csambalik, 2025), Training to build skills and confidence (Mills et al., 2017), Use of an advisor (Barnes et al., 2019)		
Knowledge	Research evidence, trials	Advances in genomic research and utilization of local biodiversity (Carretero-Paulet et al., 2025), Agronomic trials critically evaluating subsoil biochar burial (Button et al., 2022), Application of interdisciplinary and systemic approaches (Markiewicz-Keszycka et al.,	Factors related to the practice: Knowledge	21

	and long-term studies	2023), Building a stronger evidence base, particularly through field studies (Button et al., 2022), Collaborative research initiatives (Parra-Lopez et al., 2024), Conducting studies utilizing space-for-time substitutions and long-term field or chronosequence approaches for subsoil sequestration technologies (Button et al., 2022), Demonstrating that biodiversity protection does not adversely affect productivity or profitability (Markiewicz-Keszycka et al., 2023), Expanded research into sequential grazing systems (e.g. ruminants and monogastrics) (Markiewicz-Keszycka et al., 2023), Expanding research scope to include beef cattle and various impacts (Markiewicz-Keszycka et al., 2023), Inclusion of farmers in the scientific process (Markiewicz-Keszycka et al., 2023), Increased research and dissemination on long-term ecosystem services provided by cover crops (Dias de Souza et al., 2025), Increased research efforts in understudied regions (Swart et al., 2023), Increased research funding for organic agriculture (Markiewicz-Keszycka et al., 2023), Increased research on long-term ecosystem services provided by buffer zones (Dias de Souza et al., 2025), Long-term funding for research (>8 years) (Markiewicz-Keszycka et al., 2023), Long-term grazing studies (Markiewicz-Keszycka et al., 2023), More case studies demonstrating financial benefits beyond incentives (Markiewicz-Keszycka et al., 2023), Ongoing field trials and local adaptation research (Carretero-Paulet et al., 2025), Research to better understand trade-offs in practices such as no-tillage (Markiewicz-Keszycka et al., 2023), Strong scientific evidence base for C-rich wastes enabling legislative progress (Button et al., 2022), Verified or assured beneficial impact (Gemtou et al., 2024)		
Knowledge	Access to and dissemination of (tailored) information and knowledge	Access to information (Adamsone-Fiskovica and Grivins, 2024; Gemtou et al., 2024; Olum et al., 2019), Awareness campaigns (Parra-Lopez et al., 2024), Clear and consistent communication promoting environmental management alongside productivity (Mills et al., 2017), Deep ploughing (DP) is effective when used infrequently (every >10 years) (Button et al., 2022), Dissemination of knowledge tailored to different regions and contexts (Barnes et al., 2019), Efficient communication channels and efforts to raise farmers' awareness of environmental benefits (Karali et al., 2014), Government and NGOs providing information campaigns and education (Dias de Souza et al., 2025), Greater efforts to translate science into practice and build efficient communication channels (Karali et al., 2014), Improved termination practices and/or cover crop harvesting (Dias de Souza et al., 2025), Information made available at appropriate times within the farming calendar (Karali et al., 2014), Informational support (Barnes et al., 2019), Knowledge exchange and awareness programs emphasizing multiple co-benefits (Button et al., 2022), Marketing and communication campaigns to raise awareness among farmers and value chain actors (Gemtou et al., 2024), Provision of high-quality	Factors related to the practice: Knowledge	15

		information (Olum et al., 2019), Tailored communication and outreach strategies based on audience-specific knowledge and attitudes (Moxley et al., 2021), Targeted awareness-raising campaigns by public bodies and NGOs, tailored to different audiences (Moxley et al., 2021)		
Knowledge	Path dependency and existing equipment/practice base	Adoption of CSA is facilitated for farms already implementing other conservative practices (e.g. no tillage, crop diversity) due to existing equipment and experience (Dias de Souza et al., 2025), Experience with previous weather shocks (Olum et al., 2019), Extensive, diversified, or organic farming styles (Klebl et al., 2023), Farming experience (Olum et al., 2019), Greater experience, awareness, knowledge, and financial capacity (Gemtou et al., 2024), Higher level of current adoption of other PATs (Barnes et al., 2019), Knowledge of climate change and CSA practices (Gemtou et al., 2024), Previous experience with similar practices or technologies (Barnes et al., 2019)	External/contextual factors: Farm characteristics (pathways)	8
Social	Collaborative networks, cooperatives and peer learning	Building and strengthening farmer–researcher networks (Markiewicz-Keszycka et al., 2023), Collaborative frameworks enabling dialogue among stakeholders and land users (Rouet-Leduc et al., 2024), Collaborative, partnership-based advice delivery (Mills et al., 2017), Community cooperation (Klebl et al., 2023), Customized initiatives facilitating stakeholder cooperation, promoting knowledge exchange, or providing peer advice in BFFM implementation (Klebl et al., 2023), Farmer networks, associations, participatory approaches, field visits, and farm demonstrations (Gemtou et al., 2024), Industry or sectoral support (Barnes et al., 2019), Integration into farming and environmental networks (Klebl et al., 2023), Involvement in farmer clusters (Masi et al., 2022), Knowledge sharing and collaboration among farmers (Rizzo et al., 2023), Membership in a cooperative platform offering knowledge sharing, resources, technical support, and peer learning (Gemtou et al., 2024), Membership in a marketing cooperative (Barnes et al., 2019), Membership in farmer organisations or associations (Olum et al., 2019), Networking structures and peer learning platforms (Rizzo et al., 2023), Networking with other land users for knowledge sharing (Rouet-Leduc et al., 2024), Peer groups and community-based advisory initiatives (Mills et al., 2017), Peer-driven innovation and knowledge diffusion (Cammarata et al., 2024), Recognition of the value of experience-based lay assessments (Rouet-Leduc et al., 2024), Social networks and farmer organisations (Swart et al., 2023), Social networks and peer influence (Karali et al., 2014; Gemtou et al., 2024; Klebl et al., 2023), Influence of neighbouring farmers (positive relationships, experience with BFFM) (Klebl et al., 2023), Strong peer influence within farming communities (Petrovic and Csambalik, 2025), Strengthening social networks (Karali et al., 2014), Strong family and peer collaboration (local associations, neighbour	External/contextual factors: Social context (engagement in social networks)	26

		support, etc.) (Rouet-Leduc et al., 2024), Visibility of neighbouring environmental stewardship (Mills et al., 2017)		
Structural	Farm scale	Larger farm size (Barnes et al., 2019; Gemtou et al., 2024), Economies of scale / Reduced costs / Higher investment returns (Gemtou et al., 2024), Cultivated area/Production per unit area (Olum et al., 2019)	External/contextual factors: Farm characteristics (land endowment)	4
Technical	Technology availability, simplicity and compatibility	Availability of commercially viable equipment for wide-scale adoption (Button et al., 2022), Availability of contract services or shared equipment (Heller et al., 2024), CSA technologies adapted for easier use and greater compatibility (Gemtou et al., 2024), Developing affordable and accessible versions of key technologies (Petrovic and Csambalik, 2025), Digital banking and e-government (Petrovic and Csambalik, 2025), Ease of learning new solutions (Gemtou et al., 2024), Emphasis on intrinsic simplicity of technologies and compatibility of tools (Pierpaoli et al., 2013), Simplified and user-friendly technology design (Parra-Lopez et al., 2024), Technology simplification strategies (collaborating with developers to simplify user interfaces and operational aspects) (Parra-Lopez et al., 2024)	Factors related to the practice: Technical feasibility	9