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Leverage Points for Biodiversity Promotion in the Swiss Agricultural System
identified with Participatory Causal Loop Diagrams

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Abstract

Acknowledging the need for agricultural system transformation, this study uses the deep leverage point approach to explore pathways for biodiversity-friendly agriculture in Switzerland. The current system is locked in an unsustainable cycle of declining biodiversity. The issue is complex to solve due to the trade-offs related to food security. The findings highlight the pathways envisioned by Swiss experts in biodiversity promotion. The participants included farmers, biodiversity advisors, and representatives of government, agricultural, and non-governmental organisations. Utilising causal loop diagrams, diverse stakeholder knowledge was integrated to identify barriers and leverage points for improving habitat and ecological quality on agricultural land. The study underscores the potential of causal loop diagrams to facilitate system thinking for co-creating actionable solutions. However, challenges such as conflicting stakeholder perspectives, power structures, and time constraints must be navigated with purposeful participant selection and engagement. Key barriers identified for biodiversity promotion include economic constraints, rigid regulations, and polarised societal opinions, hindering collaborative action. Farmers face significant challenges, such as limited management flexibility, high administrative burdens and insufficient financial compensation. These barriers undermine farmers' capacity and motivation to promote biodiversity effectively. The stakeholders envisioned interventions strategically targeting shallow and deep leverage points. Firstly, farmers' capacity and motivation to engage in effective biodiversity promotion should be enhanced by providing alternative compensation systems. Flexible economic support for experimentation, goal-oriented payments rewarding farmers for higher quality and landscape-level collaboration for site-specific goal setting were identified as potential interventions. Secondly, the institutional capacity to provide the necessary knowledge, training and farm-tailored advice should be strengthened. Moreover, utilising consensus-building processes and including farmers in decision-making are necessary to mitigate the significant barrier related to polarised societal opinions.

Acknowledgements

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1 Introduction

This chapter sets the stage for why transformational pathways are necessary to integrate biodiversity promotion into agricultural systems. By adopting a systems thinking approach, the research delves into the dynamics of agri-environmental systems, leveraging insights from the ZiBiF pilot project in Switzerland. This initiative focuses on goal-oriented biodiversity promotion and serves as a case study to evaluate collaborative, site-specific approaches to conservation and their implications for broader agricultural landscapes. I discuss how this research adds to the ongoing conversation about making sustainable changes by finding key areas for improvement, bringing together various points of view, and developing strategies that support both nature and agriculture. This chapter sets the stage by outlining the main goals, research questions, and research methodologies.

1.1 Biodiversity decline and agriculture

The global decline in biodiversity poses one of the most pressing challenges of the 21st century, with agricultural landscapes at the forefront of this crisis. While agriculture is the fundament of food security, its intensification has led to significant biodiversity loss, converting diverse ecosystems into monocultural fields. This intensification, characterised by increased mechanisation, heavy pesticide usage, and expansion of field sizes, has disrupted habitats and altered ecological balances (Helfenstein et al., 2020; Stoate et al., 2001). The Swiss federal government's biodiversity and impact monitoring programs reveal Switzerland's declining quality and area of valuable habitats (for example, meadows and raised bogs). Near half of all habitat types in Switzerland are assessed as threatened. Switzerland has a higher percentage (37%) of threatened plant, animal and fungus species than most European countries. The leading causes are intensive use of land and water bodies, invasive species and atmospheric nitrogen inputs in the soil, especially from livestock (Gattlen et al., 2017). Biodiversity is especially low in the Central Plateau due to intensive agricultural use. Habitat structures such as groves, borders and buffer strips have been cleared in fields for structural improvements. Soils are degraded, and water bodies are drained. Low-nutrient cropland has been fertilised, and dry sites irrigated. Agricultural intensification of marginal land, such as the grasslands in the mountains, has been slower but is also visible. Cropland-associated flora is one of Switzerland's most threatened plant groups, with over forty percent classified as vulnerable (Bornand et al., 2016, as cited by Gattlen et al., 2017, p. 27). Through the intensification of land use, habitats are becoming increasingly similar. Generalist species are thriving, while specialists are in dire straits (Gattlen et al., 2017). At the same time, biodiversity is essential for ecosystem service provisioning, which is necessary for agricultural production. These services include soil fertility, water regulation, and natural pest control (Tscharntke et al., 2005). The interdependencies between declining biodiversity and intensification of agricultural production create vicious feedback loops trapping agricultural systems into unsustainable paths (Benton et al., 2021).

The trade-offs between biodiversity conservation and agricultural production are exacerbated by policies often prioritising short-term agricultural outputs over long-term ecological sustainability (Lécuyer et al., 2021). For example, using fertilisers and pesticides to increase yields negatively impacts soil health, pollinators, and other non-target species, reducing biodiversity (Stoate et al., 2001). On the other hand, conservation measures can increase farmers' financial and labour burden, making farmers unwilling to participate in biodiversity schemes. Farmers prefer short-term, low-ambition biodiversity measures that are less disruptive to agricultural production but may not lead to significant ecological improvements (Lécuyer et al., 2021). Farmers are often at the centre of biodiversity conflicts as they face pressures from market demands and social expectations (Redpath et al., 2013). Conflicts between agricultural production and biodiversity conservation are likely to continue increasing, highlighting the need to identify sustainability transformation strategies (Lécuyer et al., 2021). Farmers' dissatisfaction has grown as they face volatile profits and high input costs in combination with stringent environmental demands. The dissatisfaction has been visible in recent years as farmers around Europe have organised themselves to protest (Helfenstein et al., 2020). Effective conflict management in biodiversity conservation calls for recognising shared problems, integrating socio-political dimensions and fostering collaboration (Redpath et al., 2013). However, research often neglects the social aspects of agricultural transformations, such as different perspectives on sustainability and social imbalances (Skrimizea et al., 2020). Also, conservation decisions demonstrate a lack of integration of conflicting values and interest group perspectives (Davila et al., 2020).

Nevertheless, agricultural landscapes harbour the potential for biodiversity promotion (Tscharntke et al., 2005), presenting an opportunity for innovative approaches to reconciling conservation with production. For example, landscape-scale approaches integrating biodiversity into agricultural systems can offer a pathway to addressing biodiversity conflicts (Lécuyer et al., 2021). Co-creation of conservation strategies involving multiple stakeholders improves their effectiveness (Skrimizea et al., 2020). However, conservation measures often fail due to poor design, lack of resources or lack of stakeholder buy-in (Redpath et al., 2013). New forms of biodiversity schemes are piloted around Europe to identify optimal designs. The more common action-based schemes provide payments for specific management practices that are assumed to produce biodiversity benefits (Canessa et al., 2023). Result-based payments depend on achieving verifiable ecological results, such as the presence of indicators species or improved soil quality. However, pure result-based payment systems are relatively rare (Herzon et al., 2018). A more common version is a hybrid combining the action- and result-based schemes, for example, by providing guaranteed payments for basic actions with performance-based bonuses (Canessa et al., 2023). Action-based schemes tend to be more simple to implement and monitor (Herzon et al., 2018). However, they are criticised for lack of reflection on the local ecological and socio-economic conditions (Canessa et al., 2023). Result-based schemes allow farmers greater flexibility to choose management actions that fit their context (Canessa et al., 2023). Thus, farmers feel more engaged and incentivised to innovate (Herzon et al., 2018). However, result-based schemes typically have high transaction and verification costs and higher risk for the farmers (Canessa et al., 2023). Furthermore, they require reliable ecological indicators and expertise for implementation (Herzon et al., 2018). While findings show that farmers generally prefer result-oriented schemes, there is still a lack of knowledge regarding the optimal design of biodiversity schemes (Canessa et al., 2023).

Most of the schemes in Switzerland are action-oriented. Examples of action-oriented measures include the late cutting date of grasslands (*Wenig Intensiv Genutzte Wiese*, n.d.) and restrictions on fertiliser and pesticide inputs. Some schemes related to quality II payments are result-oriented. Thus, farmers are rewarded with bonus payments for environmental outcomes (e.g., the occurrence of specific farmland species) (Herzog et al., 2017). ZiBiF (the "*Ressourcenprojekt ZiBiF*") project, piloted in the Canton of Zurich, introduces a goal-oriented approach to biodiversity promotion. ZiBiF focuses on negotiated biodiversity goals and flexible, site-specific measures. This collaboration between farmers and biodiversity advisors is designed to align ecological objectives with farm management needs. The project strongly emphasises farm-level collaboration between the farmers and biodiversity advisors. While the biodiversity advisors (representing the project administration) offer consultation and align the farm management with regional biodiversity goals, the farmers contribute with local knowledge and balance the biodiversity goals with farm income and management needs. The advisor and farmers agree on the biodiversity goals together, but the farmer is free to choose site-specific measures. Determining the goals includes preparing a GIS-based map of the farm and surrounding area to identify areas relevant to biodiversity. The biodiversity goals are then negotiated with the farmers during a farm visit (lasting approximately 2.5 hours). During this visit, the habitat promotion areas are identified, with the consideration of the surrounding area's biodiversity potential. Key elements focused on include habitat type and quality of grasslands and orchards. A contractual agreement is signed between the farmer and the Canton, outlining the biodiversity goals and obligations of both parties. The farmers must document their management practices in a journal. However, ZiBiF is not purely result-oriented, as the farmers also receive compensation if they do not achieve the predefined goals. The farmers receive a basic contribution for their efforts and are rewarded based on a point system that considers location, habitat, and existing habitat quality. While the current action-based system has different payment levels for quality I and II, the ZiBiF project has four target qualities. The more suitable the location and the higher the quality, the more points and the higher the financial contribution the farmer receives. To eliminate the risk of loss of income, during the first two years, the farmers were compensated in case the payments were lower than in the previous system. The participating farmers are offered support and training. They receive compensation separately for activities such as training, self-assessment, and scientific monitoring interviews. The farmers are provided with evaluation tools for assessing habitat goals and checklists for self-assessing area development. Training days are offered so farmers can receive further guidance on goal-oriented and damaging management measures. ZiBiF has been piloted in the Canton of Zurich since mid-2020 and has 29 participating farmers. The ZiBiF project provided this study's main data collection channel, focusing on interviews to discover the project's actors' knowledge and mental models related to biodiversity promotion on agricultural land.

1.2 Addressing habitat and ecological quality through system analysis

Acknowledging the multiple challenges agricultural systems face, many researchers are calling for transformational sustainability change in agricultural systems and a better understanding of how to enable it (Abson et al., 2016; Anderson & Leach, 2019; Blincoe, 2022; Conti et al., 2021; Davelaar, 2021; Dentoni et al., 2017; Dornelles et al., 2022; Dorninger et al., 2020; T. G. Williams et al., 2024). I adopted a systems perspective to investigate the barriers and opportunities for enhancing biodiversity within Switzerland's agricultural landscapes. I primarily involved the actors of the ZiBiF pilot project. However, while the ZiBiF project offered an opportunity to reach experts in biodiversity promotion on agricultural land, the focus of the research was not on ZiBiF alone.

System thinking facilitates the understanding of the complex dynamics involved in biodiversity conservation (Davila et al., 2020). Food systems encompass all elements and factors from production to consumption and the socio-economic and environmental outcomes. They interact with other systems, such as the energy, mobility and societal systems. Transforming these core systems is critical for sustainability (European Environment Agency., 2017). Reaching transformational change requires shifting power dynamics (Anderson & Leach, 2019). Using the system analysis tools can facilitate the inclusion of diverse stakeholders and address power structures. These tools help to navigate conflicting perspectives and paradigms in biodiversity conservation and agricultural systems (Davila et al., 2020). The system approach integrates knowledge by considering social and ecological dimensions (Anderson & Leach, 2019) and using transdisciplinary approaches (Lamine, 2011).

Causal Loop Diagrams (CLDs) are a form of system mapping. CLDs help to discover system dynamics and identify leverage points at different system levels for transformational change. In this context, system transformation refers to a fundamental systematic change that addresses the root causes of sustainability issues, enabling a shift towards the desired state of the system (Davelaar, 2021). Figure 1 illustrates how the level of change in the system, leverage of interventions, system thinking and type of interventions align.

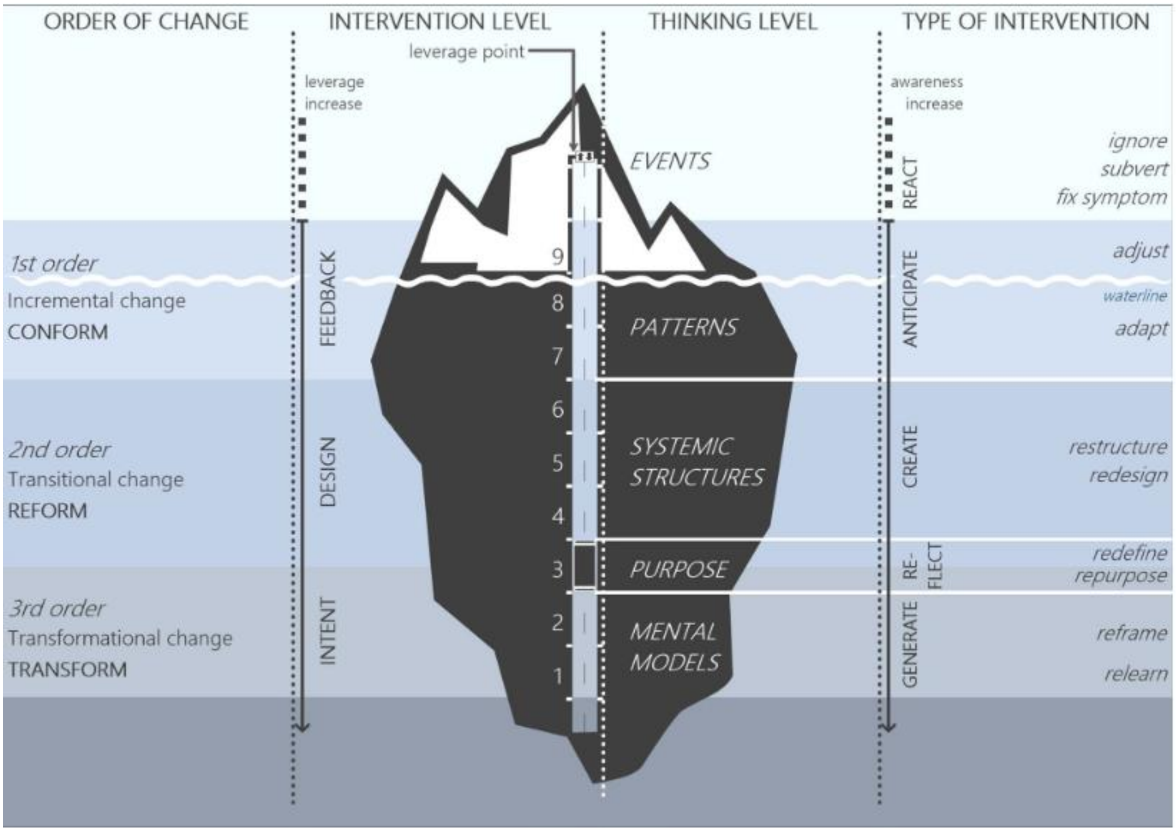

Figure 1: A model illustrating key components and processes involved in systemic transformation (Davelaar, 2021, p. 731)

From the centre to the right of the Figure 1, the iceberg illustrates systematic understanding by exploring system behaviour from visible phenomena to deep patterns. From the centre to the left, the Figure 1 illustrates intervention opportunities, categorising them into levels of impact and aligning them with types of change.

The "deeper level" leverage points for addressing sustainability challenges remain understudied (Dorninger et al., 2020). Only a few examples exist of successful sustainability transformation processes (Davila et al., 2020). Existing research underscores the necessity of moving beyond linear analyses to address these intertwined issues. System thinking and mapping emerge as promising methodologies for navigating the complexity of agri-environmental systems, enabling researchers to identify feedback loops, leverage points, and barriers. Furthermore, analysing systems and their outcomes not only allows an understanding of what the system is doing but also what it should be doing to deliver the desired changes (Davila et al., 2020). However, the tools and methodologies integrating social and ecological perspectives in food system analysis are underdeveloped. Research overly relies on easily measurable indicators rather than participatory approaches integrating diverse knowledge (Anderson & Leach, 2019). By engaging diverse stakeholders, the approaches I utilise in this research provide a platform to envision context-sensitive transformative pathways. By integrating stakeholder knowledge into system mapping and Theory of Change (ToC), this research contributes to the growing body of evidence advocating for participatory and adaptive approaches in sustainability science.

1.3 Research questions and objectives

Operating on the qualitative spectrum of system analysis, the overarching goal of this research is to identify pathways for transformation toward biodiversity-friendly agricultural systems in Switzerland. Acknowledging the inherent subjectivity, the need to contribute to the further development of the methods used and the limitations of using such methodology within the frame of my thesis work, I also reflect on the methodology. To this end, the study addresses the following research questions:

1. What are the barriers and leverage points for improving habitat and ecological quality on agricultural land in Switzerland?
2. Which transformation pathways do stakeholders envision for a biodiversity-friendly agricultural system in Switzerland?
3. What are the challenges and opportunities of using Causal Loop Diagrams in a participatory manner in agri-environmental research?

Therefore, the research aims to:

- Examine the challenges and supportive factors influencing biodiversity promotion measures experienced by the stakeholders.
- Explore stakeholders' visions for achieving biodiversity goals and overcoming systemic barriers.
- Evaluate the effectiveness and limitations of participatory system mapping methodologies in capturing complex socio-ecological interactions.

In the next chapter, I review the state of knowledge on biodiversity and agriculture, emphasising the trade-offs and synergies inherent in biodiversity promotion. The chapter 3 outlines the methodological framework, detailing the participatory approach and system mapping techniques used in this research. Chapter 4 presents the findings, focusing on barriers, leverage points, and envisioned transformation pathways, synthesising the findings and discussing their implications for policy, practice, and future research. Furthermore, I reflect on the study's contributions, limitations, and avenues for further investigation. The last chapter concludes the findings.

2 System transformation and biodiversity in agri-environmental research

Humans tend to explain and seek solutions with linear command-and-control logic. However, the world is full of non-linear behaviour, producing unexpected consequences of actions (Meadows, 2008, Chapter 4). Environmental degradation is an example of undesirable system behaviour, one which is not caused on purpose and has not been solved despite societal efforts (Meadows, 2008). Agriculture is a significant driver of environmental degradation (FAO, 2017). To find new solutions to issues that we face in agri-food systems, we need to focus on understanding the interrelationships and feedback mechanisms rather than analysing the system components individually (Ruben et al., 2018). System understanding can contribute to designing agri-environmental programs as effective interventions for sustainable agriculture.

This chapter will first provide an overview of system thinking, mapping, and transformation and continue exploring how theories of change can be created by integrating them with system mapping. Lastly, chapter 2.4 will examine research findings regarding habitat and ecological quality on agricultural land through a system thinking lens.

2.1 System thinking and mapping

A system is "*a set of things – people, cells, molecules, or whatever – interconnected in such a way that they produce their own pattern of behaviour over time.*" (Meadows, 2008, p. 2). Systems consist of elements, interconnections and a purpose. Elements are the parts of the system (actors, variables) connected, forming the system's structure to fulfil its purpose (Meadows, 2008, Chapter 1). Social systems' structure (or architecture) is shaped by the people operating in them, their personalities, worldviews, skills, resources, and societal norms and rules. Each system has a different structure and, therefore, behaves differently. We need to understand the system where we operate to envision change that brings us to the intended outcome and does not create unexpected side effects (Seelos & Mair, 2018). However, it is necessary to remember that all system maps are subjective to the mental models we form based on our understanding of the world. It would be ambitious to expect our mental models to fully represent the real world (Meadows, 2008, Chapter 4).

Dentoni et al. (2022) criticise agricultural research for persistent linearity and excessively focusing on the value chains in the agri-food sector without sufficiently considering external factors. This insufficient system approach leads to a belief that change can be planned in a command-and-control manner. Considering this criticism, Dentoni et al. (2022) recommend system thinking for identifying complementary interactions among change agents to consider system transformation beyond short-term change.

System thinking is a perspective or analytical lens to understanding reality and facilitating change (Meadows, 2008). System mapping evolved as a visualisation tool for system thinking. While not new as a method, system mapping has not yet become mainstream in agricultural (Dentoni et al., 2022) or sustainability management research (A. Williams et al., 2017). The theoretical concepts of system thinking include (Meadows, 2008; A. Williams et al., 2017):

- **interconnections** between actors and factors, forming feedback mechanisms altering effects sometimes in unpredictable ways,
- **adaptive capacity,** maintaining system resilience,
- **emergence** as an outcome of subsystem interaction, creating novel behavioural patterns of the system and
- **self-organisation** as the system's ability to adapt to changes.

As an example, the need for biodiversity conservation can be explained by self-organisation. A diverse stock of DNA is the material for evolutionary and technological development necessary for self-organisation. Self-organisation enables system resilience, which is the capability of the system to survive change by adding new physical structures or feedback loops. It is the rules defining under which conditions, how, where, and what the system can add or remove from itself (Meadows, 1999).

Feedback loops are mechanisms of the system producing the same behaviour over time (decline, growth or stability). They are created when changes in a system element influence the same element (Meadows, 2008, Chapter 1). Feedback loops can be categorised as balancing/corrective or reinforcing. While vital for system resilience, balancing feedback loops are often considered unimportant, as they may be inactive most of the time and only activate when the system is too far from its dominant trajectory. Reinforcing feedback loops brings systems to chaotic states if stronger than the balancing feedback loops. They can be sources of growth and collapse of systems (Meadows, 1999).

When considering system changes, it is vital to consider delays and buffers. Delays are often caused by buffers or feedback loops, causing oscillations in the system. Meadows (2008, Chapter 1) uses her experience with a shower, where the water heater was located in the basement, to illustrate the concept of a delay in a system. This delay refers to the time it takes for the hot water to travel from the heater to the showerhead. When she tried to adjust the temperature, she ended up with too hot or cold water because she received delayed information about the system's state. Buffers can also cause delays in our information about the system's state. Buffers are stock-stabilising, usually physical entities and not always readily observable. I will use a similar example for buffer as Meadows used for delay. I was taking a long shower at a friend's place, but the water suddenly turned cold. My friend had a small hot water tank, which acted as a buffer, delaying the information that I was running out of hot water. I was used to on-demand water heaters, thus overusing the resource due to a lack of informed intelligence about the water tank's capacity.

Visualising Causal Loop Diagrams (CLDs) helps to explore structural causes for observed trends, discover unintended consequences of interventions, and identify leverage points for desired change. Using CLDs in participatory settings draws the participants' attention to the underlying assumptions for causal linkages, the accuracy and credibility of the system's representation, and any gaps in knowledge. Exploring different mental models and how actors frame problems helps to understand that different worldviews lead to different solutions. Integrating mental models facilitates reframing the issue, producing a broader perspective on the problem. Using CLDs in participatory settings facilitates discussions among stakeholders towards the comparison and the potential need for combinations of various solutions. The connections between different problems and interactions between those solutions may also be made more tangible (Sedlacko et al., 2014).

CLDs are system maps focusing on feedback loops (see example CLD in Figure 2). Simple CLDs were used, for example, by Meadows in the Limits to Growth report in 1972. CLDs visualise system factors (elements) as variables (physical or abstract) that can increase or decrease. The factors are connected with arrows, which express the direction of causality with their polarity: positive (change in the same direction) or negative (change in the opposite direction). CLD visualisation is similar to network analysis, which can also be performed on them. Factors act as nodes and connections as edges. CLDs are primarily qualitative; they can be modified into system dynamics models (quantitative system models). Typically, the CLD has a core system engine formed by the most critical feedback loops for the question investigated (Barbrook-Johnson & Penn, 2022a).

I will demonstrate how CLDs work with a study by Angelstam et al. (2022), which used CLDs to investigate "*barriers and bridges for sustaining functional habitat networks*" (Figure 2). An example of a reinforcing "income" loop (R1) begins with external drivers increasing "*community interest in wetlands*". Follow the arrows, which all have positive polarity (change in the same direction), to "*establishment of wetlands*", "*settlement of green quality*", "*inhabitants moving in*", and "*tax money*", which again increases the "*community interest in wetlands*". At the same time, a balancing loop is in effect: the "*property price loop*" (B2). As the "*settlement of green quality*" increases, the "*property price*" also increases. "*Property price*" has a negative relationship (change in opposite directions) to "*inhabitants moving*" in, and therefore, "*inhabitants moving in*", "*tax money", community interest in wetlands*", and "*establishment of wetlands*" decreases. Thus, the "*settlement of green quality*" decreases, closing the balancing feedback loop.

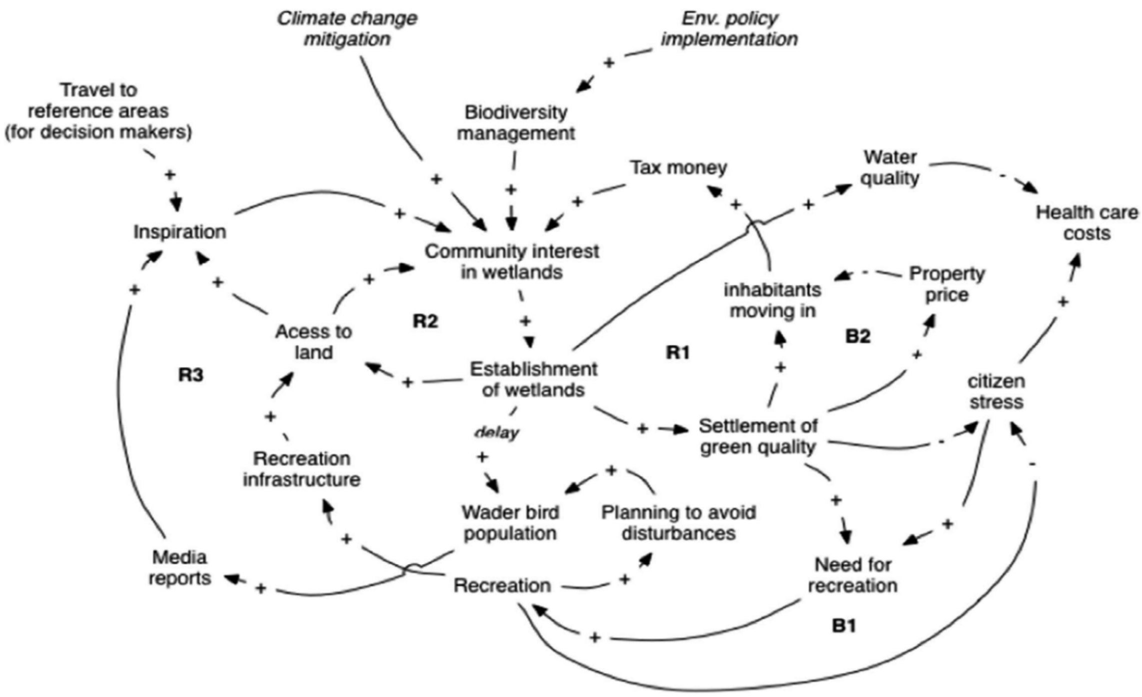

Figure 2: Example CLD: How can community interest in wader birds be increased (Angelstam et al., 2022, p. 11)?

Limitations of CLD include a restrictive focus on feedback loops, high interpretation power of the researcher, lack of quantitative analysis (Barbrook-Johnson & Penn, 2022a), the inherent simplification which comes with all system maps (Seelos & Mair, 2018), subjectivism, and focus on issues which are familiar to the participants. Therefore, the users of CLDs need to acknowledge that CLDs are not objective truths about the system but helpful framing of how the actors view the systems and issues within them (Dentoni et al., 2022). To minimise researcher bias, deep reflection processes and validation are essential throughout the CLD building process (Barbrook-Johnson & Penn, 2022a).

System maps can be generated through participatory system mapping, a process integrating knowledge of multiple interest groups. While there are diverse types of system maps, participatory system maps are typically causal models of systems forming directed cyclic graphs (CLDs or similar). The maps often form feedback loops and are analysed with network analysis. Typically, the maps consist of 50-100 factors, with time being the limitation as the mapping process could continue forever. However, in the analysis, smaller sub-maps of the system focusing on a particular problem or question are used (Barbrook-Johnson & Penn, 2022b). The example shown in Figure 2 is such a sub-system map of the CLD, created by Angelstam et al. (2022) using participatory system mapping. Developing system maps with stakeholders (as opposed to using scientific literature) provides insights into the actors' perspectives at the centre of transformations, facilitating knowledge creation regarding behaviour change and acute barriers and opportunities (Van Den Broek et al., 2024). More benefits of group system mapping are discussed in Chapter 2.3.

Complex systems form a hierarchy of subsystems with lower levels of complexity. These subsystems can be spatial, such as cities in a country, or functional, such as healthcare or educational institutions in a society. Setting system borders is often a challenging task. It is easier to set borders and separate mature functional subsystems with well-established operating patterns (Seelos & Mair, 2018). For example, Angelstam et al. (2022) divided the system they studied into subsystems based on the three themes: "*Landscape ecology and wader bird breeding success*", "*Optimal land management for wader birds*", and "*Society's interest in wetlands*". The latter subsystem is used as an example of CLD in Figure 2.

2.2 System transformation of agri-food systems

While systems constantly change, system transformation[1] refers to more fundamental changes in the system's structure. The most cited definition of transformation (Rau et al., 2018, p. 41) describes it as "*a fundamental change in a social-ecological system resulting in different controls over system properties, often mediated by changes in feedbacks that govern the state of the system"* (Chapin et al., 2012, p. 3) Researchers often refer to sustainability transformation as a desired and intended reconfiguring of systems. However, the definition of transformation by Chapin et al. does not state if the transformation is intended or not (Rau et al., 2018), indicating that systems can also change fundamentally unintentionally and into an undesirable state.

[1] "Transition" is often used as a term, similarly to "transformation" in sustainability research, but both lack a clear definition (Rau et al., 2018).

The change happening in the system tends to have a direction or trajectory. We can try to speed up, reverse, modify, or mobilise trajectories, depending on whether the direction of change is desirable (Seelos & Mair, 2018). The situation where the system becomes resistant to change by exclusion of views and practises competing with the dominant trajectory is called path dependency or lock-in. T. G. Williams et al. (2024) illustrate how the current dominant agri-food network in Europe, where farmers are heavily dependent on and influenced by powerful actors in the value chain and by state regulations, creates path dependencies that inhibit system transformations, and how alternative agri-food networks enable sustainable transformation (see Figure 3). This currently dominant agri-food network type is called "agro-industrial control" by T. G. Williams et al. (2024). It is characterised by the high power of value-chain actors above and below farmers. Retailers can set prices and requirements for product quality and farming practices, whereas input suppliers create narratives to sell their products. Gunderson (2000), who created the original ball and cup heuristic on which Figure 3 is based in the context of ecological resilience, describes the valleys as stable domains and the ball as the system. The slopes determine resilience, whereas adaptive capacity is the ability of the system to stay in the stable domain. Thus, in the example of agri-food networks from T. G. Williams et al. (2024), we can observe from Figure 3 that the agri-food control creates a deeper slope (lock-in) than the alternative networks. Ecological resilience is mainly perceived as a positive functioning of ecosystems (Gunderson, 2000). However, lock-ins are perceived as troublesome in social systems where sustainability transformation is desired.

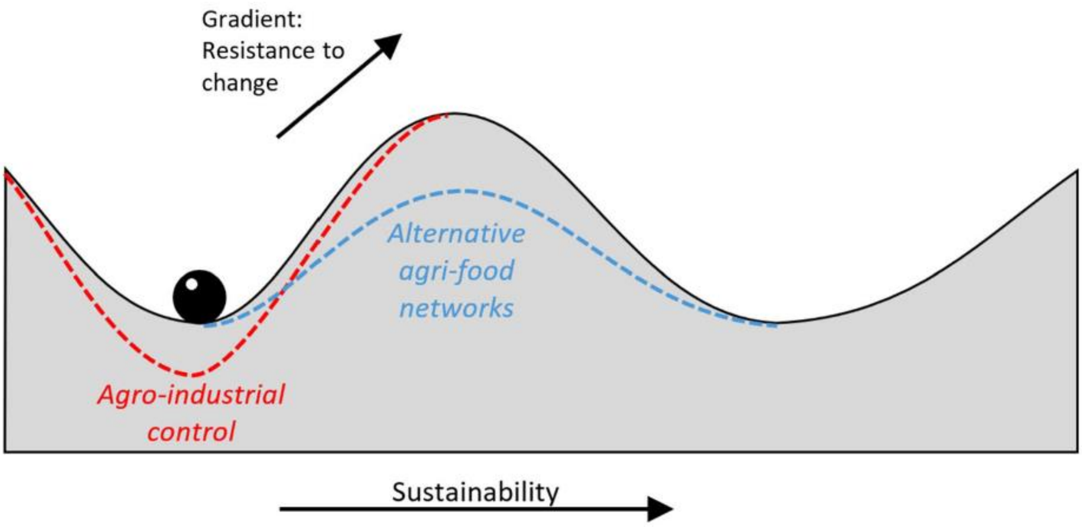

Figure 3: Schematic illustration of system stability (T. G. Williams et al., 2024, p. 3)
The ball represents the system, and the slope represents the lock-in. The deeper the slope is, the more resilient the system is to change

T. G. Williams et al. (2024) argue for context-tailored leverage points for overcoming structural lock-ins related to agri-food networks. They categorise archetypical agri-food networks based on active actors and power relationships. The study identified which parts of Europe are strongly path-dependent on agro-industrial control and where enabling environments for alternative agri-food networks exist. The agro-industrial control lock-ins were especially present in livestock-dominant regions, correlating with high levels of nitrogen and GHG emissions per hectare. Switzerland has a medium-strength lock-in related to agro-industrial control (T. G. Williams et al., 2024, Figure 3). The two alternative agri-food networks with higher transformational potential are multi-functional value chains and civic food networks:

- **Multi-functional value chains**: non-economic qualities integrated into formal value chains, for example, through formal certification.
- **Civic food networks**: actors of civil society (citizen-consumers, farmers, civil society organisations) create and govern food systems through bottom-up forms of organisation, direct sales, and combine social and political aspects.

Transformation pathways are path-dependent, working to disrupt the dominant regime – similar to lock-in mechanisms but with opposing values. Switzerland shows relatively strong enabling environments for both alternative network types (T. G. Williams et al., 2024).

Due to the strong path-dependent character of agri-food systems, the effects of interventions targeting single parts of the system are limited. The adaptive self-reinforcing and balancing feedback mechanisms keep the system on the dominant trajectory (Conti et al., 2021). The historical trajectory of agri-food systems has been towards increasing food production and has created a variety of path dependencies (Conti et al., 2021) explored deeper in Chapter 2.4.

Leverage points are a popular conceptual tool among system thinkers to identify places in systems where intervention can have a significant impact. According to Meadows, leverage points are "*places within complex systems (a corporation, an economy, a living body, a city, an ecosystem) where a small shift in one thing can produce big changes in everything"* (1999, p. 1). However, Meadows points out that finding the right leverage point or the direction in which it should change is often not intuitive. She categorised leverage points from shallow to deep (Meadows, 1999), which Abson et al. (2016) developed further (Figure 4). Meadows' leverage points can be categorised into four system characteristics that interventions can target: "*parameters", "feedbacks", "design",* and "*intent"* (Figure 4). These groups represent a hierarchy of leverage from shallowest to deepest, where interventions may be made (Abson et al., 2016):

- **Parameters** are mechanistic characteristics that are easily controlled (for example, taxes, incentives, standards or material flows).

- **Feedback** mechanisms represent the strength of the feedback loops and the length of delays.
- **Design** refers to the system's social structures, such as rules, information flows, and power distribution.
- The **intent** is the system's goal (or purpose), norms and paradigm. It is an emerging property of the system created by integrating the diverse worldviews, goals and purposeful behaviour of the actors in the system. However, the intent is not the normative goal of all the system's actors but the system's dominant trajectory, and therefore, it is not always easy to identify.

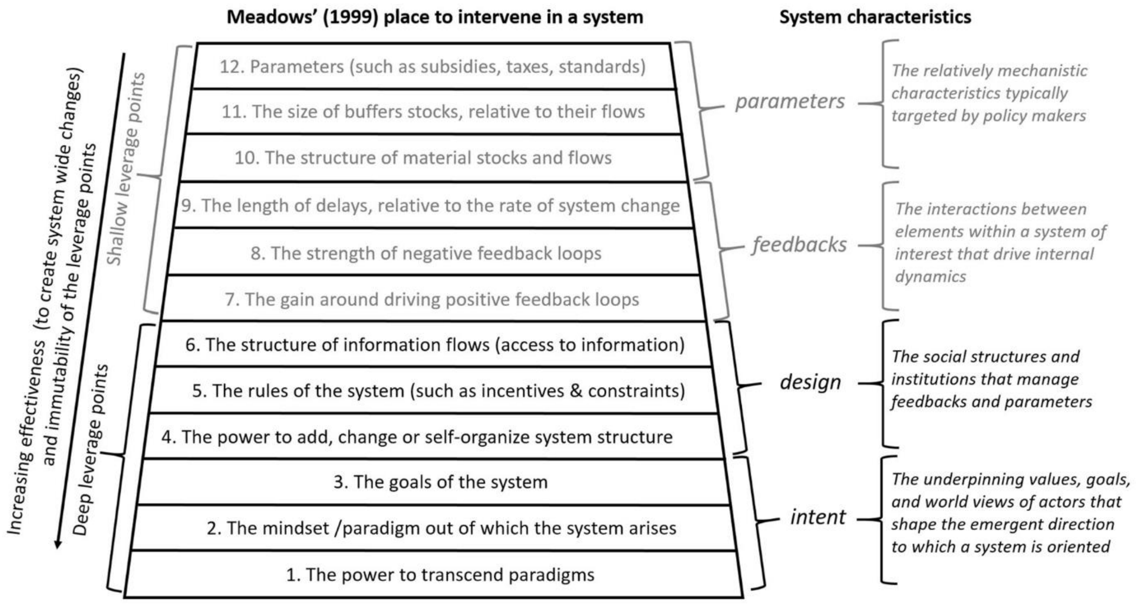

Figure 4: From leverage points to system characteristics (Abson et al., 2016, p. 32)

The interventions aimed at shallow leverage points in agri-environmental policies include agricultural subsidies and regulations for biodiversity conservation, among other things. For example, the greening of the Common Agricultural Policy is a parameter lever intervention, thus not capable of stopping biodiversity loss as the institutional design still promotes large-scale industrial agriculture rooted in the paradigm of the Green Revolution (Fischer et al., 2022). However, changing deeper-level characteristics is not straightforward (for example, changing attitudes or worldviews). While triggering parameters of the system often do not bring long-term change, they can trigger deeper leverage points (Meadows, 1999). Therefore, analysing the possible interactions between system characteristics and prioritising interventions based on cost and feasibility is necessary (Fischer et al., 2022). Also, in agricultural research, identifying leverage points can facilitate optimising multiple goals and creating synergies between the efforts of stakeholders (Ruben et al., 2018). However, the deeper the leverage point is, the more the system will resist changing it (Meadows, 1999).

Nevertheless, the leverage point perspective in sustainability research has several advantages. It facilitates

- causal thinking of change
- identification of likely places in the system where transformative change can be achieved
- understanding of interactions between different types of interventions

The leverage point perspective could advance practical and theoretical sustainability research findings (Fischer & Riechers, 2019).

2.3 Theory of change for envisioning sustainable system transformations

Theory of Change (ToC) is an approach focusing on identifying pathways to change. While there is no consensus on how ToC is defined (Stein & Valters, 2012), it provides a tool for a structured way of understanding how activities (like policy measures) are expected to drive change (Vogel, 2012; Weiss, 1995). It links activities, outcomes and the context of the initiative with the underlying assumptions of the causal relationships (Mayne, 2015). ToC has normative and causative theory components. The normative component reflects the desirable goals, while the causative part examines how the goals might be achieved (Maru et al., 2018). Typically, the evaluation process with the ToC starts with identifying the intended outcomes of an initiative, then the activities, and lastly, contextual factors that may affect the initiative's potential to achieve the outcomes (Connell & Kubisch, 1998). It is used for strategic planning, description, monitoring, evaluation, and learning (Stein & Valters, 2012).

The components of the ToC impact pathway include "*activities*", "*outputs*", "*reach and reaction*", "*capacity changes*", "*behavioural changes*", "*direct benefits*" and "*well-being changes*" (Figure 5). Change typically involves multiple pathways with many actors working simultaneously. The stakeholders often interact in attempts to bring change (Davies, 2004). The diverse stakeholders commonly hold different or conflicting beliefs, and multiple ToCs can exist simultaneously (Connell & Kubisch, 1998; Valters, 2014). Thus, making the underlying assumptions of how and why change happens visible and reflecting on the worldviews and perspectives behind them are required throughout initiatives (Maru et al., 2018).

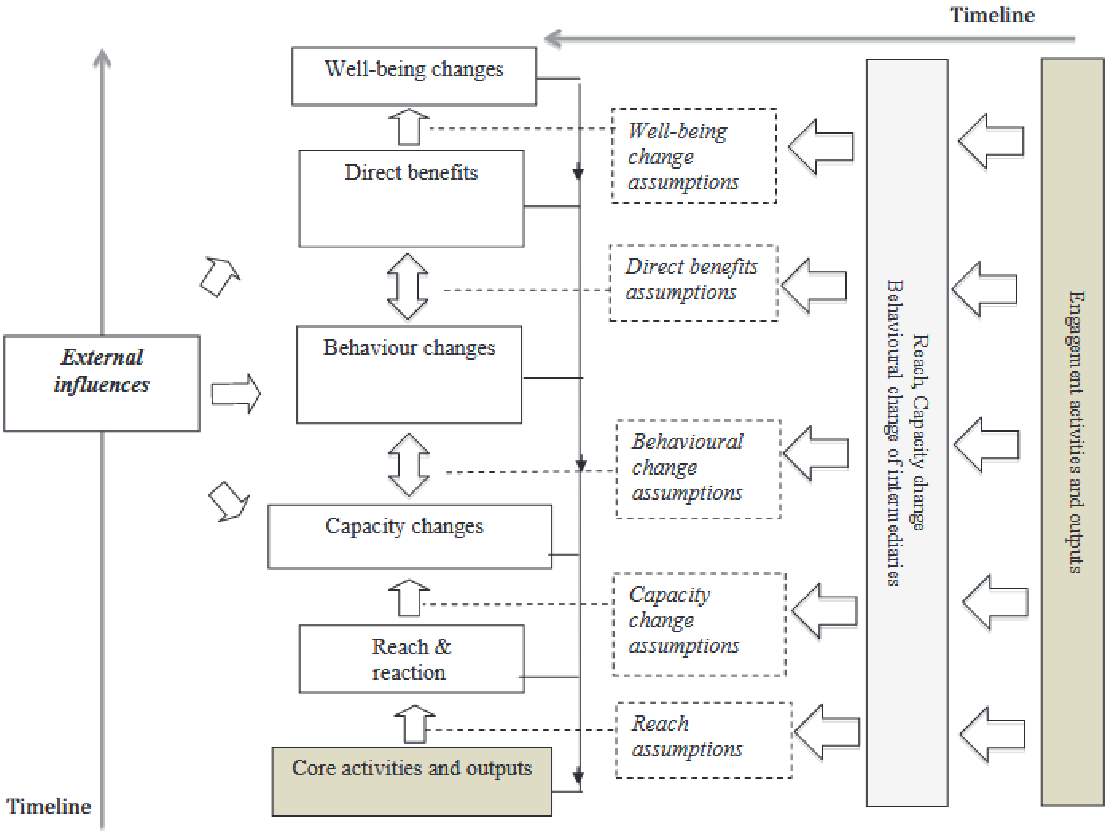

Figure 5: Basic generic ToC for multifaceted interventions (Mayne, 2015, p. 130)

According to Mayne (2015) the assumptions that should be considered for successful interventions include (Figure 5):

- **reach and reaction**: conditions for intervention to reach and be accepted by the target group,
- **change in capacity:** conditions for changing the capacity of the target group to change their behaviour,
- **behaviour change**: conditions for actual change in behaviour,
- **direct benefits**: conditions for changes to be perceived as benefits by the beneficiaries,
- **well-being change**: conditions for changes to be perceived as longer term, well-being benefits change by the beneficiary.

ToC outlines how the causal links are assumed to create various conditions that enable the intervention to increase well-being (Mayne, 2015). Making assumptions transparent allows us to question the beliefs we think are self-evident but might not apply to the context or provide the best solutions. ToC must be adapted as actors gain new knowledge as part of the ongoing learning process (Valters, 2014). However, the extent and how the assumptions should be tested is unclear. ToC can use lived experiences or social science material as evidence for the assumptions. The first might not fulfil social science standards, while the second may not represent reality sufficiently or reflect biases rooted in Western social science traditions. Thus, combining both forms of evidence is recommended (Stein & Valters, 2012).

ToC integrates research regarding behavioural change, suggesting that interventions need to target knowledge, skills, aspirations, attitudes and opportunities. Incremental changes (for example, learning new skills or adopting new practices) are considered easier to achieve than fundamental changes (changing perspectives, practices, or power structures) (Mayne, 2015). For example, farmer and consumer identity and attitudes developed based on previous experiences create path dependencies. Both farmer and consumer attitudes typically favour industrial agriculture, hampering the adaptation of sustainable technology and food consumption habits (Conti et al., 2021). On the other hand, a study in Switzerland (Gabel et al., 2018) found that farmer advisory services can influence key beliefs and motivations of farmers related to biodiversity conservation, at least if the farmers are already open to participating in biodiversity conservation. While fundamental changes are more challenging to achieve, the alignment of the measures promoted by interventions with the farmers' attitudes and practices significantly influences participation (Canessa et al., 2024). For example, productivist attitudes reduce alignment and, therefore, the adaptation of biodiversity-friendly practices (Klebl et al., 2024). Therefore, motivating farmers with conflicting values and operations takes considerable effort. However, it might not be necessary for all farmers to participate in biodiversity promotion to achieve the desired goals (Canessa et al., 2024). On the other hand, farmers with high alignment might have implemented the measures without a biodiversity scheme, diffusing the intervention efficiency due to a lack of additionality[2] (Canessa et al., 2023).

ToC was created to evaluate comprehensive community initiatives in the late 1980s and early 1990s. The development of ToC was meant to be a participatory process accounting for the complexity of socio-ecological systems (Connell & Kubisch, 1998; Wilkinson et al., 2021). While the participatory process has benefits such as consensus building and social learning[3], it also demands significant time and commitment (Connell & Kubisch, 1998; Douthwaite et al., 2009). Contradictory to the principles of participatory processes, ToC is also used to validate (rather than critically evaluate) plans and justify top-down narratives of donors rather than the

[2] Additionality refers to the economic efficiency perspective where payments should produce positive behaviour that would not have occurred otherwise (Canessa et al., 2023)

[3] Albert Bandura's Social Learning Theory posits that people learn from each other through observation, imitation, and modelling. This theory bridges behavioural and cognitive learning theories, highlighting the interplay between environmental and cognitive factors in shaping behaviour (Rumjaun & Narod, 2020).

ground realities affecting the other interest groups (Valters, 2014). Sometimes, ToC is criticised for being used from a perspective of a simplified linear causality, which does not sufficiently represent the behaviour of complex systems (Ofek, 2017) or gives false security, assuming that we can accurately predict outcomes (Valters, 2014). ToC users often view the intervention in the centre of the system without sufficiently considering the broader system where the intervention is embedded (Wilkinson et al., 2021). However, ToC has evolved to contextualised evaluation integrating system thinking (Coryn et al., 2011). Paradoxically, Stein and Valters (2012) are worried that the increasing complexity of the ToC diagrams reduces their user-friendliness. While flexibility is one of the strengths of ToC, it also means that they vary significantly from complex versions nested in system maps to simplified and linear diagrams (Wilkinson et al., 2021). Based on their literature review, Stein and Valters (2012) argue that ToC needs to be improved in terms of clarity of definition and terminology. Otherwise, it will remain just another “fuzzword”. However, no one-fits-all ToC process exists (Thornton et al., 2017).

There are multiple external factors which the intervention actors cannot control. Understanding the external factors is necessary to determine if the intervention sufficiently facilitates the expected outcomes. Therefore, in addition to the core intervention, supporting activities of the overall intervention should be integrated (Mayne, 2015). Wilkinson et al. (2021) recommend facilitating the development of the ToC with participatory system mapping. The participatory approach helps to collectively understand complex problems and envision solutions (Dentoni et al., 2022). Developing ToC with participatory mapping assists the system thinking of those involved in the process, effectively integrating complexity into the ToC (Wilkinson et al., 2021). The process clarifies where uncertainties and disagreements lay, helping to choose pathways to address the issues (Dentoni et al., 2022). Also, starting with participatory system mapping helps to open the perspective away from the program-centric view (Wilkinson et al., 2021).

2.4 Habitat and ecological quality in agri-environmental systems

Major biodiversity losses caused by agriculture began in the post-war period when traditional land use systems were intensified. On the local level, intensification has caused a decrease in crop diversity and seasonal availability, increased application of fertiliser and pesticides, higher mechanisation, and larger field sizes. At the landscape level, intensification has led to specialisation in major arable crops, conversion of grasslands into arable fields, destruction of edge habitats (due to increased field size), simplification of landscapes (spatially and temporally), disappearance of traditional extensive forms of land use and fallows, reduction of resistance to invasive species, reduction of water tables (subdrainage), and fragmentation of habitats (Tscharntke et al., 2005). Common species have become more dominant, and plant and animal communities within cropping systems have simplified. Thus, the biodiversity of agricultural landscapes has declined (Stoate et al., 2001). In addition, productivist attitudes related to intensification lead to the abandonment of less productive land (Van Vliet et al., 2015), facilitating the dominance of common species (Stoate et al., 2001). Intensification has also degraded soils due to erosion, compaction, loss of organic matter, and pesticide contamination (Stoate et al., 2001). Only part of the pesticides applied to crops affect the target, with the rest accumulating in the environment. Pesticide exposure causes various negative health effects in humans and animals (Kumar et al., 2021). However, research still lacks a complete understanding of the impact of pesticides on ecosystem functioning (Fritsch et al., 2024). Based on available evidence, it can be assumed that increased pesticide use has indirectly decreased the heterogeneity of habitats, decreasing ecosystem function (Köhler & Triebskorn, 2013). Higher fertiliser applications have affected soil biodiversity, reducing plant biodiversity and soil functioning, reducing carbon sequestration and nutrient cycling (Thiele-Bruhn et al., 2012).

On the other hand, landscape complexity has a significant positive effect on functional groups that are beneficial for agriculture (Estrada-Carmona et al., 2022). Therefore, while intensification has increased agricultural yields significantly, it may also negatively affect production through the reduced provisioning of ecosystem services, such as pollination, biological pest control, and decomposing processes (Gagic et al., 2017; Pywell et al., 2015; Tscharntke et al., 2005). Thus, biodiversity conservation is necessary for food production (Dainese et al., 2019). Meanwhile, the negative effects of agriculture are externalised, causing more significant harm to society than individual farmers. Thus, incentives for farmers to generate ecosystem services are low (Stoate et al., 2001). In addition, a better understanding and empirical evidence of the connections between agriculture and biodiversity loss is needed (Busse et al., 2021).

Nature conservation often involves habitat protection and restoration (Bunce et al., 2013; Chytrý et al., 2020). However, habitat and its related terms are often misused. While often confused with vegetation structure, it refers to the specific resources a specific species needs. Habitat quality can be understood as the *habitat's suitability to meet the needs of specific species, individuals and populations for survival, reproduction, and long-term viability,* which varies depending on the spatial-temporal scale in which it is investigated (Hall et al., 1997). Knowledge of species-specific habitat requirements is necessary if the goal is the conservation of a specific endangered species (Tellería, 2016). For example, a study in Switzerland found that while the total bird species richness grew with the increased proportion of biodiversity promotion areas in the landscape, farmland birds did not (Zingg et al., 2018). Likely, the specific habitat needs of farmland bird species were not met with the current habitat quality of the biodiversity promotion areas (Birrer et al., 2007), indicating a need to investigate farmland bird species' specific habitat quality requirements.

Habitat conservation is closely related to classifying and prioritising habitat types (Brooks et al., 2006; Bunce et al., 2013; Chytrý et al., 2020; Tellería, 2016). Habitat type refers to the *vegetation structure or potential to develop into a specific climax stage* (Hall et al., 1997). From this perspective, high-quality habitats are selected as conservation areas based on their ability to support the most species (as measured by species richness or other community indices) (Tellería, 2016). For example, ecological quality, measured with *botanical and structural diversity*, is used as a criterion for different payment levels for biodiversity promotion areas in Switzerland. Ecological quality has been found to have an impact on species abundance. For example, a study in Switzerland (Schoch et al., 2022) investigating pollinators and natural enemies highlighted the importance of ecological quality for species abundance. While the Swiss biodiversity promotion areas commonly did not positively impact most insect species, the areas with high ecological quality positively affected abundance. However, the biodiversity promotion areas typically have low ecological quality. One reason for the low quality is likely because agri-environmental measures are typically implemented on sites on the farm with low agricultural value without consideration of the quality (Klebl et al., 2024; Paulus et al., 2022). In scientific literature, ecological quality is another term that lacks a clear definition, even more so than habitat quality. It is often related to concepts such as biological integrity (similarity to natural habitats), ecosystem health (the ability of an ecosystem to remain in or return to a particular state after a disturbance) and provisioning of ecosystem services (e.g., pollination and biological pest control) (Paetzold et al., 2010).

While agriculture is primarily linked to negative effects on biodiversity, agricultural practices can also enhance ecosystem functions. Especially in central Europe, where landscapes are largely human-influenced, semi-natural agroecosystems are important for biodiversity conservation. Extensively managed agricultural sites are among the areas richest in species in central Europe. They are hosting large amounts of synanthropic species (species that live near or benefit from human-made environments), including many endangered species. Agri-ecosystems often produce high amounts of food resources for wildlife (also cause of pest outbreaks). Subsequently, the ideal for many conservation-minded people is the complex landscape structure dominated by extensive agriculture from the mid-19th century (Tscharntke et al., 2005). Despite the biodiversity value of traditional agricultural systems, such land-use types (e.g. extensive grasslands and orchards) are likely to be replaced by arable crop production under the current governmental subsidies and market trends in Switzerland (Nishizawa et al., 2022).

Measures of biodiversity conservation in European agri-environmental schemes range from restrictions on management intensity (e.g., restrictions on stock rates and agrochemical inputs), promotion of low-input farming (e.g., prevention of intensification or abandonment) and promotion and creation of landscape elements (e.g., hedges, water bodies and flower strips). The goals of conservation projects are often not clearly articulated. The lack of clear goals is problematic, as the management measures and location should depend on the objectives. The intrinsic value of biodiversity can create the will to promote it. Therefore, the objectives tend to be to conserve all species the area could sustain or to conserve rare or endangered species. In this case, the conservation focus should be on extensively managed and structurally complex regions. Protecting these areas will have the highest impact, as high biodiversity and populations of endangered species still exist. Another goal for biodiversity conservation is based on functional biodiversity, aiming to increase ecosystem services. Promoting functional diversity will have the highest benefits in areas with intensively managed, agriculture-dominated landscapes, as these areas provide low levels of ecosystem services and will benefit the most from functional diversity (Kleijn et al., 2011). However, there are synergies between promoting biodiversity to increase functional biodiversity and the conservation of rare or endangered species (Ekroos et al., 2014).

Landscape-level planning of habitat conservation is necessary because species survival is affected by the habitat connectivity of the surrounding landscape. The mosaic-like structure of suitable habitats in the landscape is measured with structural connectivity (measured with landscape metrics such as patch distance, matrix structure and corridors) and functional connectivity (measured based on the ability of species to move through the landscape) (Tellería, 2016). The trade-offs between yield loss and biodiversity promotion on agricultural land are lower when implemented at the landscape level (Tscharntke et al., 2021). Structurally complex landscapes increase the capacity of ecosystems to recover after disturbance and thus may compensate for locally high-intensity management. Complex agricultural landscapes increase functional connectivity, increasing resilience by allowing better distribution and dispersal of organisms (Tscharntke et al., 2005). Landscape complexity refers to the combination of three dimensions (Estrada-Carmona et al., 2022):

- **Composition:** Seminatural and non-crop areas, maintaining biodiversity species pools (e.g., landscapes with remaining forest patches).
- **Configuration:** Functional connectivity sustaining populations and recolonisation (for example, multi-species hedges separating fields).
- **Heterogeneity:** Spatial and seasonal crop diversity creating a dynamic landscape with quality and year-round resource availability (e.g., multifunctional land use with variability in flowering seasons).

Reduced trade-offs between agricultural production and biodiversity promotion at the landscape level can also be observed in Switzerland. Biodiversity promotion considerably reduces agricultural yields when measured at the farm level (Klaus et al., 2023). However, Zingg et al. (2024) found that the relationship between total food energy produced and biodiversity per landscape was mostly not negative. The relationship was negative for some specific species and areas with a high percentage (64-74%) of farmland. For bird biodiversity, higher food energy production was positively correlated with landscapes that had a lower proportion of farmland. However, while the species richness was not affected, there were changes in species abundance, with more common species becoming more dominant. Switzerland's average production of food energy is intermediate for Europe. The study concluded that biodiversity promotion is compatible with small-scale but intensively managed food production typical to Switzerland. Areas with the combination of biodiversity promotion areas and organic agriculture had the highest biodiversity in Switzerland (Klaus et al., 2023). Nevertheless, strategies at the landscape level minimise trade-offs more effectively than the promotion of biodiversity at the farm level through extensive agricultural systems such as organic farming (Tscharntke et al., 2021).

Biodiversity has received insufficient attention in integrated landscape management in Switzerland (Reber et al., 2022). Because individual farmers can only implement biodiversity measures within the limits of their farm and available financial compensation systems, their actions are limited to small-scale and remain ecologically ineffective without landscape-wide planning (Busse et al., 2021). Thus, for effective biodiversity management, landscape-level cooperation needs to be facilitated. Table 1 shows biodiversity-friendly measures on local and landscape scales composed by Tscharntke et al. (2021) from the scientific literature.

Table 1: Biodiversity-friendly management on local and landscape level scale (Tscharntke et al., 2021, p. 926).

Local-scale	**Landscape-scale**
• Diversity of crops, providing resources for wildlife during all seasons • Restoration of semi-natural habitats (field boundaries, hedges, ponds, trees) for increased land-use diversity • Conservation of traditional species-rich land-use systems	• Promotion of landscape complexity by restoring >20% of semi-natural habitats • Prioritise restoring simplified landscapes • Promotion of beta biodiversity with spread-out habitat patches • Increase crop diversity on the landscape level

• Ecological intensification and accurate use of fertilisers	• Reduction of mean field size below 6ha • Increase of semi-natural edge habitat length

Despite the necessity of biodiversity for food production, the trajectory of agri-environmental systems is towards declining biodiversity. The core lock-in identified in agricultural research for sustainability transformations is related to technological and production patterns creating path dependencies. Technological lock-in refers to a situation where better technological alternatives are not adopted as the dominant ones are socially embedded into the system. Technology becomes socially embedded when cognitive routines, practises, and learning patterns are established, and policy, institutions, infrastructure and production models are adapted to the technology. Pesticide use is an example where established practices supported by input supply chain regulations and markets favour chemical options over alternatives, such as integrated pest management (Conti et al., 2021). For example, a study investigating Swiss farmers' decisions to convert to organic farming (Home et al., 2019) found that organic farmers faced negative attitudes from other farmers and their families. In some cases, neighbouring conventional farmers became angry with organic farmers because their choice not to use pesticides was perceived as spreading diseases (Home et al., 2019).

Institutional structures (and actors) create lock-ins by co-evolving with the established trajectory and promoting the status quo. Also, the European Agricultural Policy (CAP) is locked in historical trajectories preventing system transformation (Conti et al., 2021). While agri-environmental schemes have been implemented to halt habitat destruction, stronger contradictory institutional support systems undermine their effectiveness. For example, incentives for production, reforestation, and wildlife management policies focused on single-species conservation have unintended rebound effects on biodiversity. Notably, the price support and capital grants part of CAP has largely facilitated the abandonment of traditional agricultural systems, reducing landscape complexity (Stoate et al., 2001). This lock-in can be observed at the individual farm level; there is a negative correlation between a high level of specialisation and participation in agri-environmental schemes (Canessa et al., 2024).

In food systems research, major lock-ins are identified in relation to power structures and politics. Historically shaped power structures in the agri-food value chains maintain the status quo, and farmers typically depend on a limited number of suppliers and buyers, limiting their choices (Conti et al., 2021; T. G. Williams et al., 2024). The lobbying of powerful corporations shapes political interests (T. G. Williams et al., 2024). In Switzerland, the failure of environmental initiatives could be due to the high political power of the Swiss Farmers Union lobbying against restrictions (Mann & Kaiser, 2023). The agri-food networks' powerful actors' interest is generally in maximising food production and efficiency, typically with intensive external input use and reduced labour needs, causing low farm-level and regional production diversity (T. G. Williams et al., 2024). The interest of politicians tends to be, in any case, focused on observable short-term gains, making measures for transformational change rare (T. G. Williams et al., 2024). According to Reber et al. (2022), political attention to biodiversity in Switzerland is given for a limited time and only to some sub-issues. The focus on biodiversity as a whole has not increased (relative to other issues). Also, especially public agricultural research largely supports the status quo of the system through a productivist, technology-centric perspective focusing on a few major crops and quick gains. In the meantime, alternative discourses are gaining much less attention, and funding (Conti et al., 2021).

In conclusion, agriculture hosts both great danger and potential for biodiversity. Agri-environmental biodiversity conservation aims to stop biodiversity loss and increase functional diversity beneficial to agriculture. Despite strong agri-food lock-ins, Switzerland also has great transformation potential towards biodiversity-friendly agricultural systems. However, better landscape-level planning and collaboration between actors at different levels and sectors are necessary to achieve biodiversity goals. Creating CLDs in a participatory manner facilitates the identification of leverage points for overcoming lock-ins in agri-food systems. Furthermore, through the process of uncovering actors' system knowledge and assumptions, ToCs can be created for the sustainable transformation of agri-food systems. Research employing these methods regarding the improvement of habitat and ecological quality on agricultural land could contribute to the much-needed system understanding of agri-food and -environmental systems.

3 Study area and methods

In this chapter, I outline the methods and study area used to investigate the relationships between agriculture and habitat and ecological quality in Switzerland. The chapter begins with an introduction to the study area and a description of the Swiss agricultural system. The research design incorporates participatory methods by employing qualitative interviews and a participatory mapping workshop. Causal loop diagrams (CLDs) and systems analysis were used to identify leverage points and barriers within the complex socio-ecological system of interest. Furthermore, pathways towards system transformation are visualised in a Theory of Change (ToC) diagram. These methods aim to provide a nuanced understanding of the factors influencing habitat and ecological quality, informed by both stakeholder perspectives and system analysis.

3.1 Canton of Zurich and agricultural system of Switzerland

Switzerland, with 35% of its land dedicated to agriculture (see Figure 6; ARE 2016, as cited by Herzog et al., 2017), is a pioneer in agri-environmental policy innovation. Farming is predominantly done on small, traditional mixed-family farms averaging less than 20 hectares. Agriculture plays a vital role in shaping the Swiss landscape (Herzog et al., 2017). Its mountainous terrain and diverse landscapes support high biodiversity, but declining habitat quality and species loss remain pressing challenges (Gattlen et al., 2017). The Canton of Zurich, covering 41% agricultural land, is a key area for biodiversity conservation and food production in Switzerland. With 15% of agricultural land designated as biodiversity promotion areas, the canton plays a crucial role in testing innovative schemes like ZiBiF. Canton of Zurich agriculture is dominated by livestock farming, and 14% of farms are certified as organic (Beltrami, 2019).

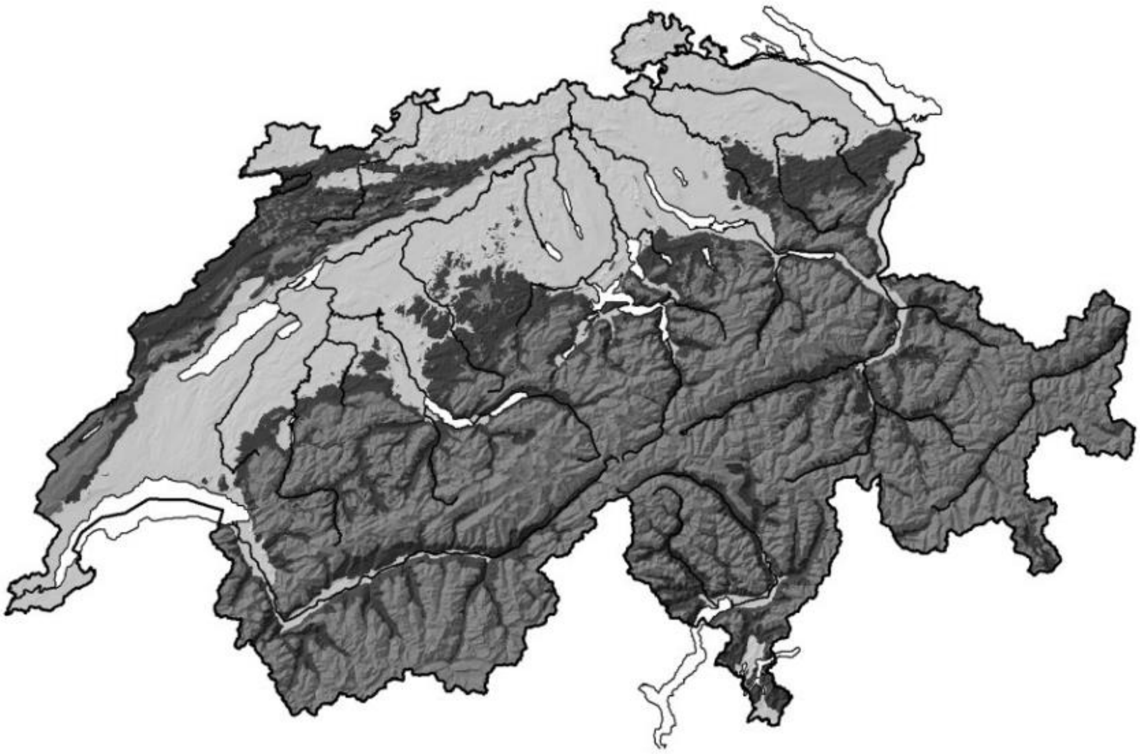

Figure 6: Agricultural production regions of Switzerland (Herzog et al., 2017, p. 387)
Arable farming (light grey) is dominating the lowlands. The mountain regions (dark grey) consist of permanent settlements and mostly grassland-based agriculture. The summer grazing areas (medium grey) are only used seasonally

Switzerland's biodiversity contributions consist of quality-based and network-based payments. Networking contributions aim to improve the networking between habitats and are paid out if the areas are created and managed according to the specifications of a regional networking project. The quality contributions are divided into ecological quality I and II. The requirements vary based on the quality and biodiversity promotion area habitat types. There are no minimum ecological quality requirements for quality I. The requirements are typically related to management practices. In quality II, the requirements are related to the presence of specific plant species and structures that promote biodiversity (BLW, 2024). Since 1999, the main tool for achieving biodiversity goals has been biodiversity promotion areas (earlier known as ecological compensation areas). Biodiversity promotion areas are part of Switzerland's direct payment system. To receive direct payments, farmers in Switzerland must fulfil proof of ecological performance. As part of this requirement, farmers must designate seven percent of their farms as biodiversity promotion areas. In these areas, the application of plant protection and fertilisers is forbidden (Birrer et al., 2007). While in 2015, about 15 percent of agricultural land was biodiversity promotion areas, only about one-third of all priority areas have desirable ecological quality (Gattlen et al., 2017). Even in areas receiving quality II-based subsidies, the qualitative goals are often not achieved. Considering this, biodiversity improvements in agricultural lands remain insufficient despite significant efforts (Agrarpolitik Ab 2022, 2018).

While the area losses of biotypes of national importance have been slowed, the quality loss due to nitrogen inputs, changes in water regimes, abandoned use and improper management has been harder to solve. The issue is especially wicked, as in most cases, the decline of habitat quality is caused by the simultaneous occurrence of different factors whose effects may be reinforced by one another—for example, the growth of settlement areas is also a driver of habitat destruction in Switzerland (Gattlen et al., 2017). While agriculture is not the only driver of biodiversity loss, it plays an important role in biodiversity conservation. Swiss agriculture still receives one of the highest levels of support globally (Agrarpolitik Ab 2022, 2018, p. 21). However, according to the assessment of FOEN, cantons would need twice the amount of funds used in 2017 to ensure legal protection and maintenance of national biotypes (Gattlen et al., 2017).

In Switzerland, citizens actively influence public policy, including agricultural policy, through plebiscites and popular initiatives. Early agricultural policies focused on the protection of agriculture, with Switzerland becoming the highest supporter of agriculture in the 1980s. Environmental concerns and international trade agreements in the mid-1980s led to reforms incorporating sustainability, direct payments, and stricter environmental standards, reducing the producer support estimate to 51% by 2017. In recent years, there has been a surge in popular initiatives addressing food security, environmental goals, and animal welfare. However, most initiatives are rejected, with changes often driven by government counterproposals (Huber & Finger, 2019).

3.2 Research design

This chapter outlines the research design employed to explore the complexities of agri-environmental systems using system analysis through CLDs and the identification of leverage points. These methodological choices are grounded in the understanding that systems thinking is instrumental in unpacking the structural causes of observed issues, the unintended consequences of interventions, and identifying potential leverage points for transformative change. With semi-structured interviews and the participatory system mapping workshop, I seek to understand how stakeholders perceive the systems they inhabit and envision change within them. The study operates on the qualitative spectrum, emphasising the purposeful selection of participants and recognising that the findings are not statistically significant but rather aimed at generating in-depth insights. The use of CLDs as a starting point for ToC development enables the integration of complexity through feedback mechanisms involvement in the broader system context (Wilkinson et al., 2021). However, it is important to note that the resulting CLD is subjective to the perspectives of the people participating in the research and is not exhaustive.

3.2.1 Participant selection and interviews

The methodological emphasis on the perspectives and input of interest groups requires the participation of a diverse range of actors as possible (Wilkinson et al., 2021). Securing diverse perspectives is essential, as actors with different types of experiences may differ in their mental models (Van Den Broek et al., 2024). Therefore, the participants were selected purposefully. All interview participants are part of the ZiBiF project. Chapin et al. (2012, p. 16) recommend involving interest groups who "*have a commitment to the place or have the power to influence the outcome of key decisions governing sustainability*". While involving all key interest groups is important, stakeholders with opposing agendas complicate finding consensus. Especially negotiating consensus on long-term sustainability goals is challenging (Chapin et al., 2012) and not in the scope of the resources in this research. The ZiBiF project offered a venue to involve actors who, while representing diverse key stakeholders, have a similar interest in improving the habitat quality of agricultural land. Furthermore, the ZiBiF project actors have experience from variable perspectives (e.g. practical, scientific, and political) with different political instruments relevant to the research questions. Thus, the participants represent experts in biodiversity promotion with different perspectives on the agricultural system.

Data collected for the ENFASYS and ZiBiF project was used to identify the research interests, help with the design and identify participants. These materials facilitated an understanding of the project and the context in which it was implemented. The materials from previous interviews and workshops with the project stakeholders gave a deeper understanding of the motivations for the project implementation, the challenges faced, and the motivation for the farmers to participate. The materials helped characterise the farmers and assist in the identification of potential research participants. Furthermore, the potential participants were invited to answer short online survey questions, where they indicated interview language (German or English), self-identified their discipline (academic, practitioners, government officials, and NGOs), years of experience, age, gender, primary role in the project, and preferred form of interview (in person or online).

The selection process was adapted from Okoli and Chitu (2004) and helps to minimise selection bias and to guarantee that the results represent a variety of expertise and perspectives. The selection process consisted of the following steps:

1. Identification of relevant disciplines or skills
2. Identification of relevant organisations
3. Selecting potential representatives for the selected disciplines or skills and organisations
4. Contacting experts identified and asking them to nominate potential participants
5. Ranking of potential participants
6. Inviting potential participants in the order of the ranking order until the desired number is reached.

I selected farmers for the interviews based on finding representatives whose efforts to promote biodiversity were considered successful examples in the project, farmers with extensive experience in biodiversity promotion (participation in different projects as an indicator), representation of controversial perspectives on the project, representatives of both male and female farmers, representation of different age groups and representatives of both organic and conventional farmers.

The goal of the interviews was to identify and understand the factors influencing habitat and ecological quality of agricultural land and to explore the relationship between these factors in the context of Switzerland. The semi-structured interviews lasted approximately one hour per person, with five minutes of introduction, 50 minutes of interview questions and five minutes for closing the session. The introduction consisted of explaining the goals of the research and interview and a short explanation of system mapping. The guiding questions had five themes: established practices and structures, external pressures and contextual factors, goal-oriented biodiversity promotion/ZiBiF and influence of system factors at the farm level. The themes were organised around the multi-level perspective framework plus user level (Deviney et al., 2023). The guiding questions can be found in Appendix A: Interview questions. The participants were free to choose which guiding questions they answered to which extent to allow focus on the topics in which they felt they had the most expertise. The open-ended questions facilitated reflection of factors affecting outcomes and the external context. Encouraging participants to consider border system components (e.g. not only aspects related to the ZiBiF project) allows for capturing context that can influence or be influenced by the interventions and ensures that the main interests of the stakeholders are included (Wilkinson et al., 2021). While the participants answered the questions, the interviewer visualised her interpretation of the answers as a mind map (mental model). The first question of the interview was to ask the participants to define habitat quality, as this was the focal point of the system map. The participants were asked to confirm if the visualisation represented their ideas and perspectives, and they were encouraged to suggest more factors and connections to the mind map. Factor refers to variables (can increase or decrease) representing the concepts described by the participants. The factors can be abstract (for example, hope) and do not need to be directly measurable. The connections between factors represent causal relationships. While there is a possibility to mark connections as unclear or complex, the aim was to understand if the causality is positive (change in the same direction) or negative (change in the opposite direction) (Wilkinson et al., 2021). The closing of the session included engaging the participants in investigating the mind map to confirm again that it represents their understanding of the system and explaining what the next research steps are.

The mental models of the interviewees were visualised using software (Mental Modeler) during the interview to facilitate system thinking and more precise and in-depth expressions by drawing attention to underlying assumptions for causal linkages, making knowledge gaps visible (Dentoni et al., 2022; Sedlacko et al., 2014) and making interpretations of the interviewer transparent, allowing simultaneous validation. While group participatory mapping is often recommended (Wilkinson et al., 2021), the CLD was constructed from individual interviews. While this method might not benefit from shared understanding and collaborative learning[4] to the same extent, it allows individuals to express their views more openly without the influence of other participants (Deviney et al., 2023). The interviews were constructed according to the advice of Wilkinson et al. (2021). Therefore, the focus point of the mapping was habitat and ecological quality on farmland, the desired outcome factor of interest to the participants.

[4] System mapping helps diverse stakeholders develop a common understanding of the complexity of the system they are analysing. It creates a shared conceptual framework that aligns participants' views on the system's structure and dynamics (Davila et al., 2020).

However, while the interviews were done with the actors of the ZiBiF project, the exercise design considered the whole system rather than just the ZiBiF project. Only after the whole agricultural system was reflected on were factors related to the ZiBiF project focused on. Taking the focus first away from the intervention helps to avoid a programme-centric view, which ToC is criticised for (Wilkinson et al., 2021).

The data collected from the interview consisted of a mind map visualising the factors and relationships and the interview transcripts with the meanings of the factors and explanations for the relationships. The interview protocol was tested once in English and once in German before the data collection began. The person conducting the German interviews was trained in the same session. While German was the mother tongue of all the participants, some were fluent enough to conduct the interview in English with me. To improve readability and ensure clarity, minor corrections to grammar and phrasing were made to the transcripts while preserving the original meaning of the statements. Direct quotes are indicated with participant identifiers. The participants were assigned into group types with an identification number linked to the mind map and transcripts. The group types were farmers and biodiversity advisers. The rest were assigned to a group called stakeholders, as a more detailed description of their stakeholder group would critically reduce their anonymity.

When the participant preferred to be interviewed in German, an employee from FiBL, fluent in Swiss German and trained with the interview protocol, conducted the interview and translated the transcripts and mind maps. Four of the participants were interviewed in German. A reflection practice was applied after each interview, where the interviewer considered how the interview process succeeded (for example, sufficient output, whether the interviewee was comfortable answering the questions and possible interview bias influencing the answers). The first two times, I did this by discussing the interview process with my supervisor from FiBL and the rest independently. For the interviews done in German, I reflected on them with the translator.

Participating in the research was voluntary. I informed the participants regarding the data use and their rights to, for example, view data collected regarding them and to withdraw from the research at any given time. The information was provided in written form and orally before the interviews. The participants were asked for informed written consent for data use and to record the interviews and the workshop. I present the findings in an anonymised way. The findings were summarised in German and disseminated to the research participants. After that, the participants were offered two one-hour sessions at different dates for giving feedback and asking for questions and clarifications. Alternatively, feedback and questions could be provided in written form. This was done before the thesis deadline so that I could reflect on the feedback and consider any possible ethical issues reflected in the feedback.

3.2.2 Building causal loop diagrams from mental models

I followed the advice of Barbrook-Johnson and Penn (2022a) for building the CLD. The interview data was analysed to gain insights into the social realities and the construction of meanings through an interceptive understanding of the transcripts and mind maps. The aim of building the CLD was to create a subsystem of the agricultural system of Canton of Zurich, focusing on habitat and ecological quality on agricultural land. The challenge was to find a balance between a sufficient level of detail while maintaining the understandability of the CLD. Some of the stakeholders participating in the participatory system mapping workshop, where the CLD will be used, do not have extensive experience with the CLD language and the workshop has limited time to explain the relationships in the CLD. Thus, creating a relatively simple version of the CLD was necessary (Wilkinson et al., 2021).

The first round of transcripts and mental models coding was done to identify factors and their meanings. I used a deductive-inductive coding approach, using initial categories as a starting point while adding additional categories during the process (Bingham, 2023). The initial categories were the same as the interview themes adapted from Deviney et al. (2023), who used the Multi-Level Perspective framework with an additional farm level. Therefore, the initial categorisation was landscape (the institutional level including societal norms, policy, environment and general economy), regime (technical infrastructure, rules, and behaviours of a specific system), niche (the innovation), and farm (the user level). The farm level was added as it is central to understanding how land managers make and execute land use decisions (Von Haaren et al., 2012). In the inductive categorisation, the factors were categorised into factors related to ecology and habitat quality, economy and markets, knowledge and education, public opinions and values, agricultural practices, policies and regulations, ZiBiF-specific policies and regulations and farmers and farm attributes. The categorisation facilitated identifying and grouping similar factors across the different interviews based on the factor names and descriptions. After grouping, a common name was selected, and a description of the factor was created based on the interviews.

In the next coding round, causal relationships between the factors were identified. After that followed the prioritising narratives and descriptions of the causal relationships from the transcripts and mind maps. In the case of conflicting statements, the more popular one was selected. If the connection was unclear based on the interviews, literature about the topic was used as a reference. When feasible, a broader category was selected to represent multiple factors (for example, feelings of being valued, appreciated and respected were combined into one factor), reducing the total number of factors. Factors mentioned at least in three interviews were prioritised, as this resulted in a bit over 20 factors, close to the desired size of the CLD as recommended by Barbrook-Johnson & Penn (2022a, p. 53)

The first version of the CLD was built on Vensim, with the prioritised factors and respective connections. The more detailed relationships were prioritised over direct relationships. For example, if interview A said that knowledge improves habitat quality and interview B said that knowledge increases farmer's motivation, which increases habitat quality, option B was used. In addition, factors that did not change the behaviour of the CLD or were not part of feedback loops were removed until the CLD contained 20 or fewer factors. This resulted in some of the "external" factors that were not part of any feedback loops and factors that did not have sufficient information to create relationships to be removed. The main feedback loops of the CLD were identified and checked against the prioritised relationships to ensure that they represented them. If a removed factor had multiple mentions by stakeholders and significant importance in the scientific literature, it was added back to the CLD. Any illogical relationships were rechecked based on the mind maps and interviews and corrected so that the CLD was logical and representative of the prioritisation.

In the next step, the CLD was exposed to feedback. The CLD was reflected on together with the supervisor from FiBL. Based on the reflection, I modified some factor names and definitions for better understandability and improved the argumentation and logicality of the relationships. The reflection was done in combination with translating the CLD into German for the validation process. The CLD was validated by the participants with an online survey (Google Forms) in German and adapted from the "member-checking" method recommended by Deviney et al. (2023). The survey consisted of pictures of the main feedback loops in the CLD with a short explanation and statements regarding the relationships. The participants could either agree or disagree with the statements. If the participants disagreed, they were asked to explain the reason. At the end of the survey, the participants could see the complete CLD and give general feedback. The factors and their meanings were provided in English and German as a PDF attached to the invitation email. The participants had one week to answer the survey. The CLD was modified if three or more actors or one of the people whose interview data was the basis of the relationship disagreed. The modification was made based on the feedback provided in the open-ended questions. The modified CLD was again reflected during the translation process with the FiBL supervisor to improve the understandability.

3.2.3 Systems analysis and development of the theory of change

A two-hour participatory online system mapping workshop was organised to identify the factors and causal links in the system map that are most significant for the outcome. Two hours seems like a suitable time as longer sessions seem to lead to growing fatigue and dissatisfaction among the participants. The workshop was facilitated in German by FiBL employees. The facilitators focused participants' attention on the guiding questions and controlled modifications done in the CLD. The workshop length, number of participants and facilitation style are based on the recommendations of Sedlacko et al. (2014).

In addition to the interview participants, actors from NGOs focused on biodiversity conservation (Birdlife and ProNatura) and agroecological transformation (Biovision) were invited. The first part of the workshop (30-40 minutes) consisted of an introduction of the participants (name, region, and interest group), an agenda, an explanation of how the CLD was constructed and an example of how feedback loops work. The second part of the workshop was done in smaller groups of around four people. The first part of the group (about 30 minutes) work consisted of understanding and modifying the CLD. The task of the next part was to identify leverage points for improving habitat quality. After the first two tasks, the facilitator of each group shortly (1-2 minutes) described the changes made to the CLD and leverage points to identify in the plenary. Back in the group session, the participants were then asked again if they wanted to change something in the CLD. The last task (about 10 minutes) was to identify interventions which would trigger the leverage points identified.

Because CLD made in a participatory manner tends to have inconsistencies, duplicities and under-developed structures (Sedlacko et al., 2014) I reviewed the modifications after the workshop. The modifications were only implemented if the new connections or factors were not already included in the CLD in some form (prioritising the more complex relationships) and if they were consistent with the rest of the CLD. The modified CLD was no longer validated with the participants due to lack of time. As participatory system mapping can, in theory, continue forever, time and resource limitations are typically the reason for stopping the process (Barbrook-Johnson & Penn, 2022b).

While the leverage points identified in the workshop were prioritised, the interview and workshop transcripts were also coded again. The coding aimed to identify barriers and interventions and get more insights into how they impact the system. By a barrier, I mean the current state of a factor preventing desirable change (improvement in habitat and ecological quality), while lock-in refers to structural constraints (T. G. Williams et al., 2024). To understand the impact and importance of the leverage points, the CLD and factors were analysed:

- Network analysis to rank factors based on betweenness, closeness, eigenvector, in-degree and out-degree centrality.
- Identification of reinforcing and balancing feedback loops
- Identification of lock-in mechanisms created by the feedback loops and barriers

- Identification of the impact of the leverage points on the feedback loops
- Categorisation of the leverage points and interventions based on Meadows' (1999) classification

The network analysis was performed in Gephi, a free visualisation and exploration software for graphs and networks. Network analysis uses techniques adapted from social network analysis and system dynamics to explore key structures, relationships and leverage points. I applied the following measures (Murphy & Jones, 2020):

- **In-degree**: “signal” factors (with a high number of incoming connections) speed of change indicate the system’s volatility
- **Out-degree**: a measure of potential power (high number of outgoing connections)
- **Betweenness**: Indicates bottlenecks which must be considered in change strategies
- **Closeness**: Indicates barriers that may not be easily changed despite changes elsewhere in the system
- **Eigenvector**: Indicates potential leverage points by telling which influential factors impact other influential factors

However, these measures should be used cautiously, as they rely on assumptions conflicting with the logic of CLDs and thus may wrongly indicate leverage points. For example, the most commonly used measures, betweenness and closeness centrality, do not consider:

- the direction and polarisation of relationships,
- that the flows in CLD may not take the shortest path,
- that the factors might overlap and interact.

Therefore, especially betweenness and closeness centrality are not fit for leverage point identification. Eigenvector may give more accurate results (Crielaard et al., 2023). However, as shown by Murphy and Jones (2020) network analysis can help identify the qualities of factors, giving insights into which factors might act as barriers or leverage points. Therefore, the network analysis is combined to support the leverage point identification by the stakeholders.

The feedback loops were identified manually by rearranging the CLD in different ways. This was first done in Vensim, but I later changed to Miro. The logic behind the feedback loops was checked and corrected if it conflicted with the narratives from the interviews. The categorisation to balancing and reinforcing feedback loops was also done manually based on the visualisation. Each feedback was given a letter (B for balancing or R for reinforcing) and a number for identification. I calculated using Excel how many feedback loops each factor is part of and how many factors are part of each feedback loop (see Table 4 in Appendix C: Tables).

The leverage points were analysed based on their centrality and impact on feedback loops. Each feedback loop where a leverage point is included was analysed. If the leverage point was not part of any feedback loops, the feedback loops it triggered were identified and analysed. The potential of the leverage point was analysed based on the change in the system towards the desired direction (increase of habitat and ecological quality).

While ToC can consist of detailed plans with steps of cause and effect, this research aims to reflect on the complexity of change through a system perspective (Stein & Valters, 2012). Following the instructions of Wilkinson et al. (2021) the CLD was rearranged in iterative cycles. While the process was drawing on the interest groups' input, it was not possible to do the whole process in a group setting. Firstly, the original CLD was evaluated and improved against the stakeholder feedback and the modified CLD from the workshops. The interventions were added to the CLD on the left side, while the outcomes were moved to the right side. Key connections and factors for the outcomes were highlighted. These were the leverage points identified in the workshop and other factors on the causal pathway. The final ToC was created using the central factors and connections. The links between the ToC and border map were then reflected on to identify key external influences, feedback mechanisms and trade-offs.

The final CLD, leverage points, barriers and ToC were reflected on in an open and informal setting with the ZiBiF project actors. I organised two separate one-hour online sessions consisting of 20-minute presentations of the key findings and 40 minutes of discussion. Guiding questions covered aspects such as the agreement and perceived importance of the leverage points and barriers, the level of complexity and completeness of the CLD, the experiences with the participatory system mapping, sufficiency of the interventions and agreement with the assumptions behind the causal linkages. I used the feedback to reflect on the research findings. However, no changes were made anymore to the structure of the CLD.

4 Results and discussion

In this chapter, I present the results of the study and discuss the findings structured around the three research questions presented in Chapter 1. The analysis integrates insights from interviews with key experts, participatory mapping workshops, and scientific literature, highlighting system factors, relationships, and dynamics relevant to biodiversity-friendly agriculture in Switzerland. In Chapter 4.1, I introduce the research participants, emphasising the perspectives that shaped the study. In 4.2, the focus is on the data collected and analysed regarding the factors influencing habitat and ecological quality and their relationships. Chapter 4.3 builds on the previous chapter by discussing the system dynamics and feedback loops created by the factors and their relationships. In Chapter 4.4, I address the first research question by identifying barriers and leverage points. The second research question is addressed in Chapter 4.5, which introduces the interventions identified by stakeholders and outlines the Theory of Change (ToC). Chapter 4.6 answers the last research question by evaluating the effectiveness of CLDs as a tool for fostering stakeholder engagement and identifying systemic dynamics. Study limitations and opportunities for further research are reflected in Chapter 4.7. Together, these findings contribute to understanding the systemic and methodological dimensions of promoting biodiversity on agricultural land in Switzerland.

4.1 Participants

Ten people were interviewed for one hour per person. Of these, half represented the ZiBiF project team, and half were farmers. I first interviewed two leading and central actors in the ZiBiF project. In addition to the interview, I consulted them on recommendations for participants. Furthermore, participation in a ZiBiF meeting and training session offered an opportunity to introduce the research to many project team members and farmers. More details regarding the interviews can be found in the Appendix C: Tables, Table 2.

The five participants from the ZiBiF project team represented five different organisations: the cantonal office of agriculture, non-profit organisations focusing on agricultural advisory, the cantonal institute of agricultural education, and the farmers' association. Despite the careful selection of interview participants to represent different interest groups, most self-identified themselves as practitioners, with the definition of "e.g. farmers, agronomists, consultants, and technical advisors who contribute valuable real-world experience and practical perspectives". The high representation of practitioners might be because of the high proportion of farmers (5 participants) and advisors (3 participants). One person identified themselves as academic: "e.g. researchers and educators affiliated with universities, research institutions, or academic organisations who contribute to the theoretical and empirical understanding of the system." and one as "government official: representatives from local, regional, or national government bodies responsible for policymaking, regulation, and oversight related to agriculture and environmental sustainability". Another reason for the high self-identification as "practitioners" might be that while some might identify with multiple interest groups, the survey allowed only selecting one.

The farmers participating in this research represent farmers interested in and motivated to promote biodiversity. The participants' involvement in the ZiBiF project shows their interest in promoting biodiversity. In addition, interviews done with the farmers at the beginning of the ZiBiF project show that most farmers, and all the ones who participated in the interviews of this research, value biodiversity and might promote it at some level also without participation in the ZiBiF project. One of the interviewed farm managers was a woman, and the rest of them were men. Two farmers were relatively young (25-34), while the rest were 45-54 (one farmer) or 55-64 (two farmers). Three farms were organic, and two were ÖLN (Ökologischer Leistungsnachweis). The farms are located at elevations 410 to 710 meters in the Canton of Zurich. The estimated workload of the farms varied from one to six full-time workers. Most of the farms produced a diverse range of products. Almost all the participants kept animals, most commonly dairy cows, but also goats, chickens, and bees. Cultivating cereals and other field crops was also common. Two of the farms cultivated vines.

Nine people participated in the workshop, of which five also participated in the interviews. In the workshop, participants could identify with multiple interest groups and the following groups were represented: researchers, farmers, representatives in agriculture, agricultural politicians, biodiversity advisors, and employees of NGOs. In total, 14 people participated in the research. The participants were labelled as farmers (five) or advisors (four). One of the advisors also identified as a farmer. If the participants did not belong to the first two groups (the representatives of government officials, agriculture, NGOs and scientists), they were labelled as stakeholders (five).

4.2 Factors and relationships

In this chapter, I explain the factors selected for the final CLD and their relationships with references to the statements of the participants. In total, 21 factors were selected for the final CLD (

Table 3 with definitions of the factors in the Appendix C: Tables), with 45 connections (Figure 14, page 70). These connections form the structure and feedback mechanisms of the CLD explained in the chapter 4.3. The factors are indicated with quotation marks; for example, in the following way, the increase in "factor A" decreases "factor B".

4.2.1 Habitat and ecological quality and habitat management

As pointed out in Chapter 2.4, there is considerable confusion about the meaning of habitat-related terms. The German term used in the ZiBiF project and interviews was *die Qualität eines Lebensraums*. The descriptions of the term in the interviews often included biodiversity, species diversity, soil health and structural aspects, such as hedges, trees, shrubs and flowering meadows. Most farmers connected habitat quality to the practical aspects they implemented in the ZiBiF project. One participant argued that while habitat quality and biodiversity are mostly seen and measured by the occurrence of rare species, "*the ability of life creation*" would be a more desirable goal (Farmer nr. 3). Improving functional biodiversity and the ecological quality of habitats seemed to be equally important, if not more important, than habitat quality. Therefore, I changed the goal from improving habitat quality to including the ecological quality of habitats.

I selected the factors “habitat management efficiency” and “habitat management effort” to map the impact of farmer's actions aimed at improving habitat and ecological quality (Figure 7). If there is a lot of effort but the farmer is doing wrong things (no “habitat management efficiency”), the quality does not increase. If the farmer does not see any effort to manage the habitat, there is also no quality improvement, even if the farmer could, in theory, be efficient. The effort represents the total amount of measures a farmer implements to improve habitat and ecological quality. Efficiency refers to the useful ratio of the effort performed to produce the desired outcome. Therefore, the more effort the farmer puts into habitat management to reach the desired quality, the less efficient the habitat management is. In addition, the usefulness (thus efficiency) is increased if the implemented measures also have other benefits, such as increased ecosystem services facilitating agricultural production. Details of how I developed the mapping of these factors based on the interviews and validation can be found in the Box 1, in Appendix B: Research memos.

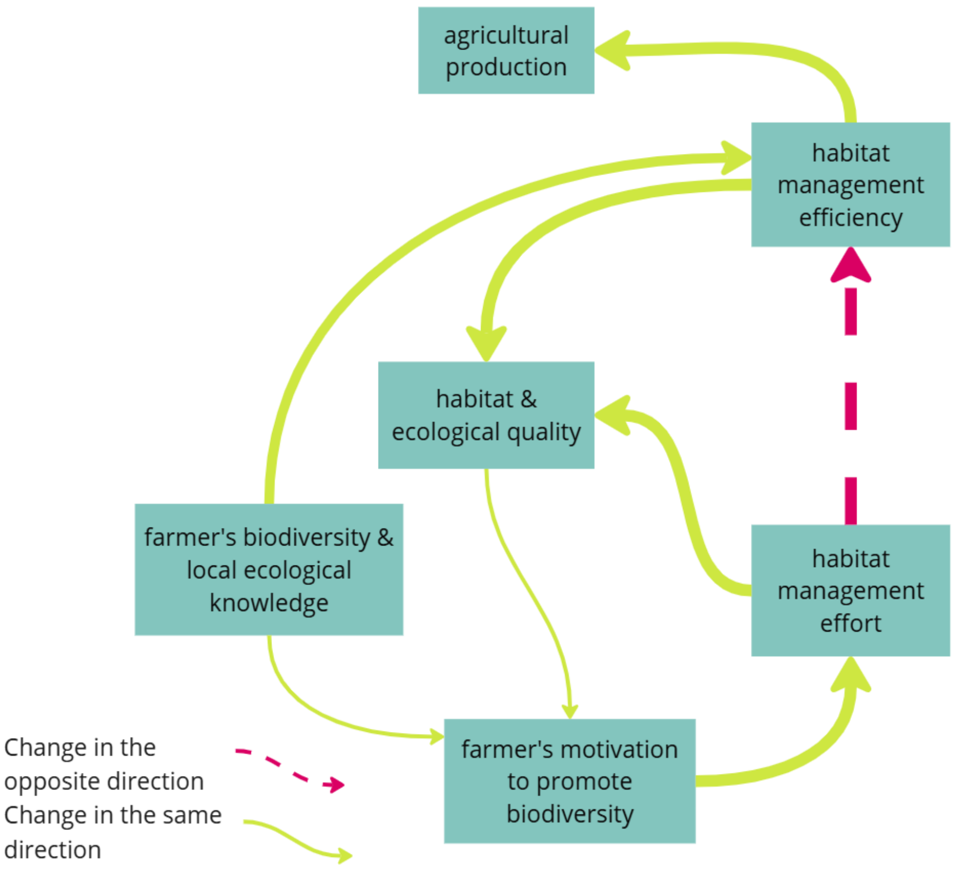

Figure 7: Habitat management effort and efficiency

"Habitat management effort" and "efficiency" illustrate farmers' actions for promoting biodiversity. Efficiency is the useful ratio of effort. The more effort the farmer sees for the same benefits, the less efficient they are. Benefits refer to the desired improvement in habitat and ecological quality and increased ecosystem services that are good for agricultural production. Farmers' biodiversity promotion efforts typically have low benefits for agricultural production and high trade-offs related to opportunity cost[5]. Thus, typically, an increase in "habitat management effort" leads to reduced "agricultural production". However, increasing "habitat management efficiency" may reduce opportunity costs and synergies between agricultural production. Thus, if efficiency is increased simultaneously with efforts, "agricultural production" is increased.

A positive connection between "habitat and ecological quality" and "farmer's motivation to promote biodiversity" was made, as two farmers and one project team member noted that noticing high quality in their farms often motivated farmers. The farmers connected this to increased enjoyment of their work:

> *"Working in the field becomes much more enjoyable. You look around with open eyes. Sometimes, I just stand there and watch. Somehow, the rush and stress fade away." (Farmer nr. 2)*

In short, farmers' habitat management influences "habitat and ecological quality" by the useful ratio of effort they are seeing. Farmers are more motivated to promote biodiversity when they observe their land's increased habitat and ecological quality. Additionally, "habitat and ecological quality" are influenced by "efficiency of input use", "obligatory protection of farmland", and "landscape complexity", as will be explained later.

4.2.2 Farmer's biodiversity and ecological knowledge

Several participants mentioned that increasing habitat and ecological quality on farmland is a complex process demanding significant knowledge and effort from the farmers:

> *"If you want to get more biodiversity, it's not like if I want to get more wheat. It's easy to put on more fertiliser and spray out the weeds. But in biodiversity, it doesn't work the same way. You need to understand the system, how things work, how different varieties grow, or what they need for growing, and not every year is the same. So, you need to start and go and have a look at the biodiversity grassland, and it's harder to succeed in biodiversity." (Farmer nr. 1)*

The biodiversity advisors (nr. 1 and 3 in the interviews and nr. 4 in the workshop) mentioned that for the farmers to be motivated to promote biodiversity, they need to understand why it is meaningful. Knowledge regarding functional biodiversity, how to increase it, and how it impacts ecosystem services provisioning was considered especially important. However, if the farmers do not have the flexibility to apply their knowledge, they acquire less knowledge:

[5] Opportunity cost refers to the value of the next best alternative forgone when a decision is made to allocate resources to a particular choice or activity. In other words, it's the cost of what you give up when you choose one option over another (Riera-Prunera, 2014).

"*The ones who have the strict rules, they are not actually really interested in my knowledge, because they just want to know what the rules are."* (Advisor nr. 3)

In particular, "farm-tailored advice and training" with a goal in combination with "management flexibility" increases "farmers' biodiversity and local ecological knowledge". "Farm-tailored advice and training" also increases the "feeling of appreciation":

> *"So that they can ask someone if they have a problem. But also, that someone actually cares about them, someone who visits the farm and somehow takes care of things." (Advisor nr. 1)*

In short, the interviews highlighted, that the amount of "farmer's biodiversity and local ecological knowledge" and allowing them to apply it increases habitat and ecological quality. "Farm-tailored advice and training" and "farmer's motivation to promote biodiversity" increase "farmer's biodiversity and local ecological knowledge". Additionally, knowledge was mentioned as a necessity for the farmers to engage in "site-specific management", as well as a motivating factor, as discussed later. More details regarding how management flexibility influences the connections of knowledge to other factors can be found in Box 2 in Appendix B: Research memos.

4.2.3 Site-specific management

"Farm-tailored advice and training" with a goal in combination with "management flexibility" were also experienced as useful by farmers for "site-specific management":

> *"If you look at the areas together and then decide together from a technical point of view: Which measures are right here now? This landscape cannot be dictated by Bern or from the Zurich office. That's rubbish; it doesn't promote quality. It's up to the farmer and the advisor on the site. You must have this freedom." (Farmer nr. 5)*

From the interviews, I identified that "site-specific management" is relevant for "habitat management efficiency" and "input use efficiency". The conclusion was validated in the workshop:

> *"You need site-adapted management for both, otherwise you have neither profitability in high-intensity agriculture nor in nature conservation." (Farmer nr. 3)*

"Site-specific management" was indicated to increase "habitat management efficiency" in three ways:

- by selecting the right site at the farm for the regional conservation goal
- or by selecting a fitting goal for the site chosen by the farmer
- and by adapting the biodiversity measures to the goal and potential of the site

An opposite to the site-specific management would be one-fits-all solutions, which were perceived as ineffective. An example is the National Hay Day (*Wenig Intensiv Genutzte Wiese*, n.d.) in the current direct payments system, restricting farmers from mowing before the 15th of June: *"Because everybody cuts their biodiversity across on the 15th of June, there's nothing left for the insects"* (Farmer nr. 1)

On the other hand, if the goal is agricultural production, "site-specific management" increases "efficiency of input use". It was connected to concepts such as precision and regenerative agriculture, which aims at efficient input use:

> *"If you can maximise this biomass productivity and the soil cover and the soil health, and you can do that with the least inputs, that's when you're really successful." (Farmer nr. 3)*

The most often mentioned aspect of agriculture affecting habitat and ecological quality was input use intensity. Most participants focused on pesticides and fertilisers, but a few also mentioned machinery (e.g., the intensity of mowing and tillage). The impact of input use intensity was mostly perceived as negative to the habitat and ecological quality, and reduction in input intensity was mostly perceived as negative to the agricultural production and profitability. However, not everyone accepted the relationship to be this simplified. Some pointed out that, in some cases, fertiliser or mowing can be beneficial for habitat quality:

> *"Biodiversity is complex, and it depends on what the goal is, and which management practice would be good or not. Sometimes fertiliser is good, and it enhances biodiversity in an area." (Advisor nr. 2)*

Also, the relationship between input intensity and profitability was questioned:

> *"Intensive farming methods are not more cost-effective; there are extensive farms that are much more efficient because they have fewer human resources that can be used elsewhere, lower operating costs, etc." (Advisor nr. 2, validation survey)*

The selected factors for describing the relationships between input intensity, "profitability", "habitat and ecological quality" are "efficiency of input use" and "agricultural production". By "efficiency of input use", I refer to the system's efficiency in converting inputs into outputs. Thus, at the highest input use efficiency, profits from agricultural production are maximised with minimum input use. "Efficiency of input use" increases "profitability" by reducing input costs (e.g., minimising pesticide and fertiliser costs) while increasing "agricultural production" (the optimal number of inputs at the right time). At the same time, it indirectly benefits "habitat and ecological quality" as agricultural pollution is reduced. Furthermore, "profitability" is increased by "agricultural production" measured in its market value. Further details about the factor "profitability" and how it is formed can be found in Box 3, in Appendix B: Research memos.

The other aspect of site-specific management and setting site-specific goals is relevant at the landscape level. For example, one farmer highlighted the importance of keeping areas with high agricultural potential for production purposes and conserving endangered species in marginal areas, highlighting the role of soil and conflicting objectives between food production and the conservation of rare species:

> *"If it's a great soil, which usually would be forest and best for any human nutrition, then there should not be any trial to get some marginal land established on it. But, on the other hand, when you have an area which is actually non-yielding and has issues... that's a different story." (Farmer nr. 3)*

Another of the farmers expressed the need for selecting site-specific goals based on the biodiversity potential:

> *"If a farm is located in a valuable landscape area, then it should develop nature conservation in the same way that a vineyard develops its vines on a vineyard site. That is part of agriculture: nature conservation." (Farmer nr. 5)*

While the focus was framed differently, both farmers expressed the need for landscape-wide strategies for biodiversity promotion.

In essence, suppose the farmer has "management flexibility" and "farm-tailored advice and training"; then the "farmer's biodiversity and local ecological knowledge" increases "site-specific management". If directed towards agricultural production, "site-specific management" increases the "efficiency of input use". If directed towards biodiversity promotion, it increases "habitat management efficiency". Furthermore, "site-specific management" reduces the "trade-offs between objectives", especially if applied on the landscape level.

4.2.4 Farmer's free capacity: resources, time, and freedoms of farmers

I selected "farmer's free capacity" to describe the resources, time, and freedoms farmers do not use or lose to perform core business activities. For example, revenue-generating activities reduce time and resources but are necessary for the farm business not to go bankrupt. On the other hand, most farmers in Switzerland are dependent on direct payments, which require farmers to follow specific management practices, reducing their freedom:

> *"This direct payment system in Switzerland, this is very strong. I mean around 50% of the income of a farmer comes from direct payments. And farmers are actually complaining that the system is so complex and so strict that they cannot even breathe." (Stakeholder nr. 2)*

The strict regulations and rules (lack of "management flexibility") were often mentioned as problematic. In addition, reduced management flexibility was generally perceived to reduce farmers' motivation to do anything more than the minimum requirements for biodiversity: *"I* *think also for the biodiversity, it's one of these that the farmers do just the minimum. And that's it. Because they have a lot of other rules, they have [to follow]"* (Farmer nr. 4)

In connection to the ZiBiF project, farmers mentioned the increase in management flexibility to impact motivation through the increase in their possibilities to do something different: "*We do a lot for biodiversity because we were able to change."* (Farmer nr. 1)

Administrative efforts were mentioned as a time-consuming activity reducing farmers' motivation for biodiversity promotion:

> *"So, it's no longer easy not to make any mistakes and not to forget anything, to comply with all these rules. So, it takes quite a lot of effort to deal with it and not make any mistakes. Nowadays, you sit in front of the computer for a relatively long time to familiarise yourself with the rules." (Farmer nr. 5)*

Profitability increases free capacity. While available free capacity does not automatically mean that farmers are motivated to promote biodiversity, reduced free capacity would reduce the motivation:

> *"When I earn nothing, my farm also goes bad, bad, bad, bad. I think that's also one of the motivations of the farmers because they don't see that you can earn something when you do something about the biodiversity." (Farmer nr. 4)*

Financial compensation was often pointed out by many as the primary motivator for farmers to promote biodiversity: *"If biodiversity is financially interesting, we're going to put more time into that and resources."* (Farmer nr. 1). Also, consumer demand for sustainability labels was assumed to increase financial compensation for biodiversity promotion:

> *"I think the IP[-Suisse] we have this integral production from Switzerland, and they have some points you have to achieve in biodiversity, and then you get a slightly higher price for the product. (Farmer nr. 4)*

However, I assume certification typically reduces management flexibility and increases administrative efforts (e.g., regulations in IP Suisse and organic), as confirmed, for example, by Karali et al. (2014).

Altogether, "management flexibility" and "profitability" increase "farmer's free capacity", and "administrative effort" reduces it. "Farmer's free capacity" is necessary for farmers to engage in "site-specific management" and for "farmer's motivation to promote biodiversity". However, increased free capacity does not automatically mean farmers will engage in site-specific management or biodiversity promotion.

4.2.5 Impacts of societal disputes on farmers

Polarisation of opinions was often mentioned in the context of political discussion regarding biodiversity promotion. The most often mentioned aspect was the high focus on food production, but a few farmers also mentioned the strong environmental attitudes of consumers. It was indicated to impact how farmers perceive their value in society and appreciation for their work.

The perceived trade-offs between biodiversity promotion and food security were highlighted as an important factor hindering biodiversity promotion:

> *"This is the major conflict, and it's all they say in politics. This is about biodiversity and production. More biodiversity means less production and more imports from outside. So, this is what is complained about all the time. And therefore, it's really a struggle actually for it." (Stakeholder nr. 2)*

Lack of cooperation was seen as the outcome of the polarisation of opinions but was mentioned only by one participant and, therefore, not included in the diagram:

> *"There is a lack of cooperation at eye level, of the farmers' association, together with the nature conservation organisations, they prefer to argue with each other rather than work together." (Farmer nr. 5)*

One farmer also mentioned how the focus on food production impacts farmer's reputation if they decide to change to extensive farming methods:

> *"When we switched to organic, we were the only ones here, and we were laughed at. People said: With the way they're farming, with this extensive farming, they won't last long." (Farmer nr. 2)*

The agricultural incentive system is still also primarily focused on food production, creating trade-offs between selecting different incentives:

> *"There are sometimes trade-offs between objectives. Now, you can also make a relatively large amount of money from animal husbandry, which then partly contradicts the promotion of biodiversity. So, then there are the classic disincentives that come from somewhere or that cancel each other out." (Stakeholder nr. 1)*

Currently, farmers are also perceiving more pressure from consumers to be sustainable. However, the pressure also feels unjust as there is a lack of willingness of citizen-consumers to see effort on their part, including the willingness to pay for sustainable products:

> *"They always want farmers to be more sustainable, but they do not pay the price for it… So, everybody says, yeah, that's good, more biodiversity. But they go all over the world on holiday by plane." (Farmer nr. 1)*

The lack of appreciation for farmers' professional role as managers of the land was also mentioned concerning the obligatory protection of land farmland. **"**Obligatory protection of farmland" refers to nature conservation areas established on land owned by a farmer. Many perceived the obligatory protection of farmland as problematic:

> *"This has a direct influence, partly positive but also negative. The positive influence on land and habitat quality is, of course, the individual area that is protected, which has a positive influence on habitat quality. But, the background to this is that these areas are always owned by someone, often by a farmer. And he is not happy when the whole thing is protected. In order to defend himself against this protection requirement, in quotation marks, he makes sure that he has as little quality as possible in his biodiversity promotion areas. Then, it is not protected, and that has a negative impact on the habitat quality, i.e. on the overall habitat quality, not on the individual area. (Stakeholder nr. 1)*

One workshop participant (Advisor nr. 4) suggested additional connections related to the "feeling of appreciation". "Financial compensation for biodiversity promotion" was pointed out to increase the "feeling of appreciation", and the "feeling of appreciation" was mentioned to increase farmer's motivation to promote biodiversity.

Overall, the "polarisation of opinions" is created by the conflicting perspectives of different stakeholders ("consumer demand for biodiversity labels" and "agro-industrial value chains") and perceived "trade-offs between objectives". "Site-specific advice and training" and "financial compensation for biodiversity promotion" increase the "feeling of appreciation". Meanwhile, "obligatory protection of farmland" reduces farmers' "feeling of appreciation". When farmers and their representatives feel that farmers' professional roles and efforts are threatened and underappreciated, they take a defensive stand, "polarising the opinions" further and reducing "farmer's motivation to promote biodiversity". Thus, polarisation hinders the development of progressive solutions as there is a lack of cooperation.

4.2.6 Other factors

The factors "agro-industrial value chains" and "landscape complexity" were added due to their importance in scientific literature. A few factors were excluded due to the ambiguity of their impact and a lack of meaningful connections, even if three or more participants mentioned them (see Box 5 Appendix B: Research memos as an example). Market and global-level external factors were not getting much attention in the interviews.

Only one participant (Stakeholder nr, 1) clearly stated a landscape perspective, considering connectivity and fragmentation of habitats as a vital factor for habitat quality. However, because of indirect mentions of the importance of considering landscape when choosing biodiversity promotion areas and the high importance of landscape complexity in the scientific literature (Estrada-Carmona et al., 2022), it was also included in the CLD. “Landscape complexity” increases “habitat and ecological quality” (Estrada-Carmona et al., 2022).

Despite the presence of industrial agri-food value chains and power structures related to them in Switzerland (T. G. Williams et al., 2024), only two participants mentioned the influence of product requirements (Stakeholder nr 1 and farmer nr. 2). One of the two also mentioned the importance of markets and value chains (Stakeholder nr. 1). One organic farmer also mentioned that he experiences less market pressure due to the organic certification (Farmer nr. 5). A few participants mentioned the overall focus on food production as problematic. Because of the importance of “agro-industrial control” in the scientific literature (Conti et al., 2021; T. G. Williams et al., 2024), the factor “agro-industrial value chains” was included in the CLD. It refers to networks within the agricultural and food production sector, characterised by power dynamics favouring large-scale, input-intensive farming and efficiency-driven practices. It increases the “polarisation of opinions” due to the high focus on food production and reduced “landscape complexity” due to the increased agricultural intensification (Conti et al., 2021; T. G. Williams et al., 2024). Further details regarding why the factor “agri-industrial value chains” was included in the CLD can be found in Box 4, Appendix B: Research memos.

Land managers are influenced by global megatrends indirectly through drivers impacting local factors. Examples of global megatrends acting as drivers of change are global trade agreements, changes in land governance and policy and climate change (Helfenstein et al., 2020). Global drivers may be less visible and be ignored more easily by the system actors at the local scale. The only global-level factor mentioned by the stakeholders was international market pressures, which were not perceived as an issue due to Switzerland's market protection regulations.

In summary, “agro-industrial value chains” and “landscape complexity” were added to the CLD. However, for instance, global-level external factors, the complex subsystems related to markets, landscape complexity and aesthetic preferences were not included in the CLD. The lack of stakeholder insights on the global-level factors, market dynamics, and landscape complexity may indicate knowledge gaps, restrictive problem farming, or a perceived lack of importance for these factors.

4.2.7 Interdependencies between factors

It is crucial to consider the interconnected relationships between the factors. In conclusion, the interconnected factors are:

- **“Habitat and ecological quality”** are impacted by “farmer's habitat management effort” and “efficiency”. In addition, “efficiency of input use”, “obligatory protection of farmland”, and “landscape complexity” affect habitat and ecological quality.
- **“Farmer’s free capacity”** refers to the financial resources (“profitability” and “financial compensation”), time (“administrative effort”) and freedom (“management flexibility”) farmers do not use in their core business activities.
- **“Site-specific management”** requires “free capacity” and farmer’s “biodiversity and local ecological knowledge”.
- **“Profitability”** is formed by “agricultural production” (revenue) and “efficiency of input use” (reduced cost). Alternative revenue could be “financial compensation”.
- **“Farmer's motivation to promote biodiversity”** requires “free capacity” and a reason to be motivated (“farmer’s motivation to promote biodiversity”), such as knowledge about the benefits, financial compensation or enjoyment of habitat and ecological quality of one's own farm.
- **“Polarisation of opinions”** is formed by the perceived “trade-offs between objectives”, dividing perspectives (and interest groups) between those who want to maximise food production and those who blame the first ones for biodiversity loss.

In the next chapter, I will show how the factors and relationships identified from the interviews create the system structure and dynamics.

4.3 System dynamics and feedback loops

This chapter presents the feedback mechanisms created by the factors and connections. I also consider how the current trends identified in the interviews and workshops influence system dynamics. The CLD has 17 feedback loops, of which four are balancing (Figure 8), and 13 are reinforcing (Figure 9, Figure 11, Figure 10, and Figure 12). Further details regarding the feedback loops and factors can be found in Table 4 in Appendix C: Tables.

“Farmer's motivation to promote biodiversity”, “habitat management effort”, and “habitat management efficiency” are part of all four balancing feedback loops (Figure 8). “Agricultural production”, “profitability”, and “farmer's free capacity” are part of three of the balancing feedback loops (B1, B2, B3, Figure 8). These three feedback loops illustrate how farmers are not motivated to continue promoting biodiversity if it continues to reduce their free capacity, as highlighted in the interviews. B4 (Figure 8) illustrates a situation where the farmer sees lots of effort to improve the habitat but fails due to a lack of efficiency. The failure reduces the farmer’s motivation to continue. However, there were no examples in the interviews where the balancing feedback loops would be activated in the opposite direction.

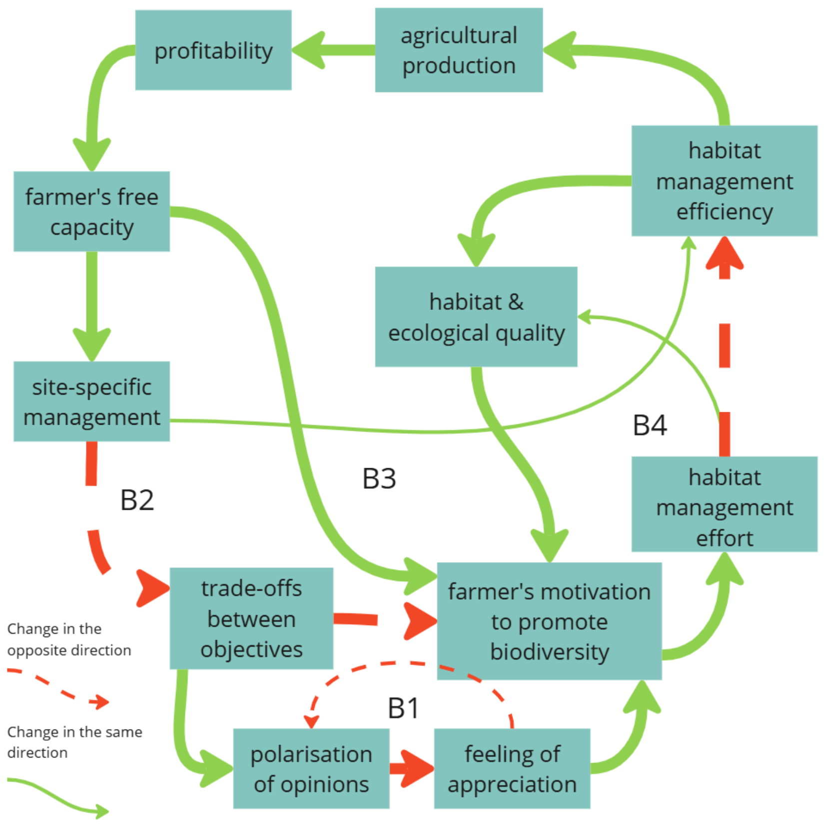

Figure 8: Balancing feedback loops

Figure 8 illustrates all the balancing feedback loops in the CLD. They all depend on the relationships between "farmer's motivation to promote biodiversity", "habitat management effort", and "efficiency". B4 could be interpreted as a failure to increase the quality due to a lack of efficiency. B1, B2, and B3 show how the farmer is not motivated to continue biodiversity promotion if profitability and farmer's free capacity are reduced. In B2 and B3, the farmer engages in site-specific management, which reduces the trade-offs between biodiversity promotion and agricultural production. As the farmers can fulfil multiple normative goals simultaneously, they feel less judged and, thus, more appreciated by society. Nevertheless, because of the declined profitability, the farmer is not motivated to continue biodiversity promotion.

The current trend indicated in the interviews is that biodiversity promotion is not perceived as profitable. Therefore, "farmer's motivation to promote biodiversity" is low. The impact of the balancing loops on the reinforcing loops in the Figure 9 is that the farmer does not engage in habitat management (R11), does not acquire biodiversity knowledge (R10) and does not engage in site-specific management for biodiversity promotion (R7). Therefore, the farmer does not observe and enjoy increased habitat and ecological quality, and their motivation is reduced furthermore. As a result, the impact of the balancing feedback loops on the reinforcing loops creates lock-in mechanisms preventing changes, which would significantly improve agricultural lands' habitat and ecological quality.

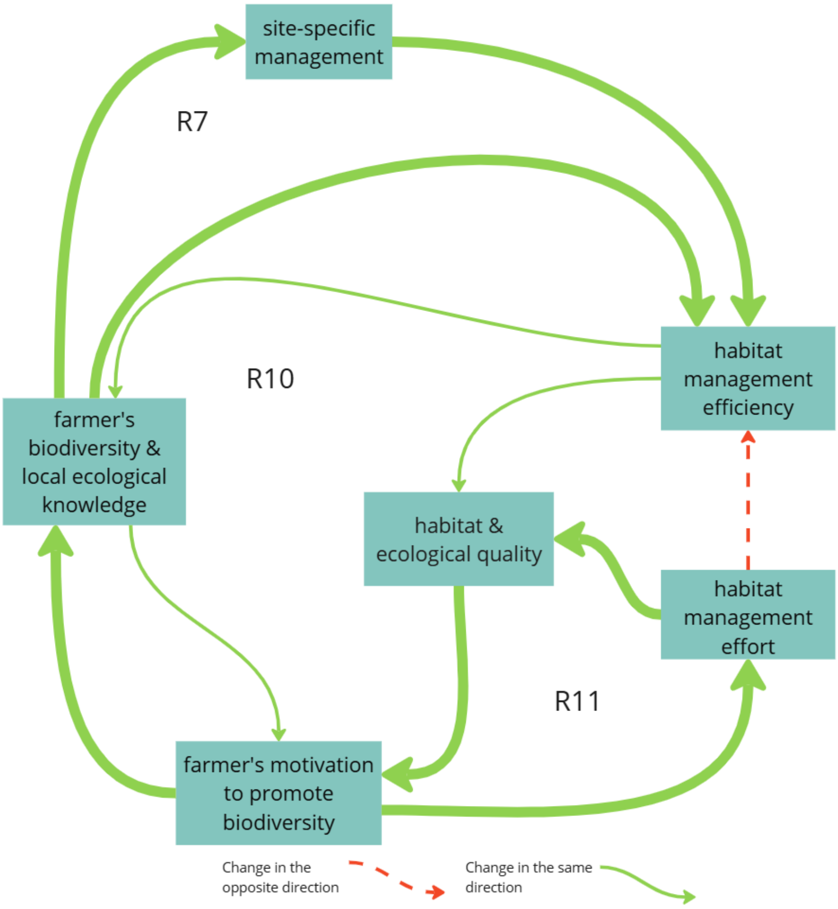

Figure 9: Habitat management success

Figure 9 shows three reinforcing feedback loops related to (un)successful biodiversity promotion. In R11, the farmers are motivated to continue promoting biodiversity as they observe the improved habitat and ecological quality. In R10, the farmers successfully applied their knowledge to increase the efficiency of habitat management. In R7, the farmer applied their local ecological knowledge to engage in site-specific management, also increasing efficiency. If the reinforcing change is in the direction of reducing the factors, the reinforcing loops illustrate how failure demotivates farmers from continuing.

Assuming that the balancing feedback loop is not active and that the "farmer's motivation to promote biodiversity" is increased. In this case, the farmers will increase their habitat management efforts (R11) and acquire more biodiversity knowledge (R10). The farmer will also apply their local ecological knowledge, engaging in site-specific management (R7). Therefore, all three reinforcing loops in Figure 9 increase "habitat and ecological quality". Another aspect related to R11 is how farmers perceive their own capability to successfully carry out the measures (perceived behavioural control), which, along with the perceived environmental effectiveness of the measures, are important determinants for implementation. Education, skills, and experience increase perceived behavioural control (Klebl et al., 2024). Thus, I assume that when farmers gain more experience and observe the effectiveness of the measures, their motivation to continue biodiversity promotion increases. However, biodiversity promotion is a complex process that demands large amounts of effort and knowledge from farmers to be successful. Therefore, the balancing feedback loops generally activate, and the desired direction of the reinforcing loops does not become dominant.

R3 (Figure 10) shows a reinforcing loop where the reduction in "profitability" due to ineffective habitat management activities reduces the "motivation of a farmer to promote biodiversity". Due to the balancing effects of B2, B3 and B4 (Figure 8), farmer's motivation to promote biodiversity and knowledge acquisition remains low. Therefore, the "efficiency of habitat management" is low, and the impact of any effort that the farmer sees for biodiversity promotion is negative to "agricultural production". Thus, the farmer's motivation keeps decreasing until they stop biodiversity promotion.

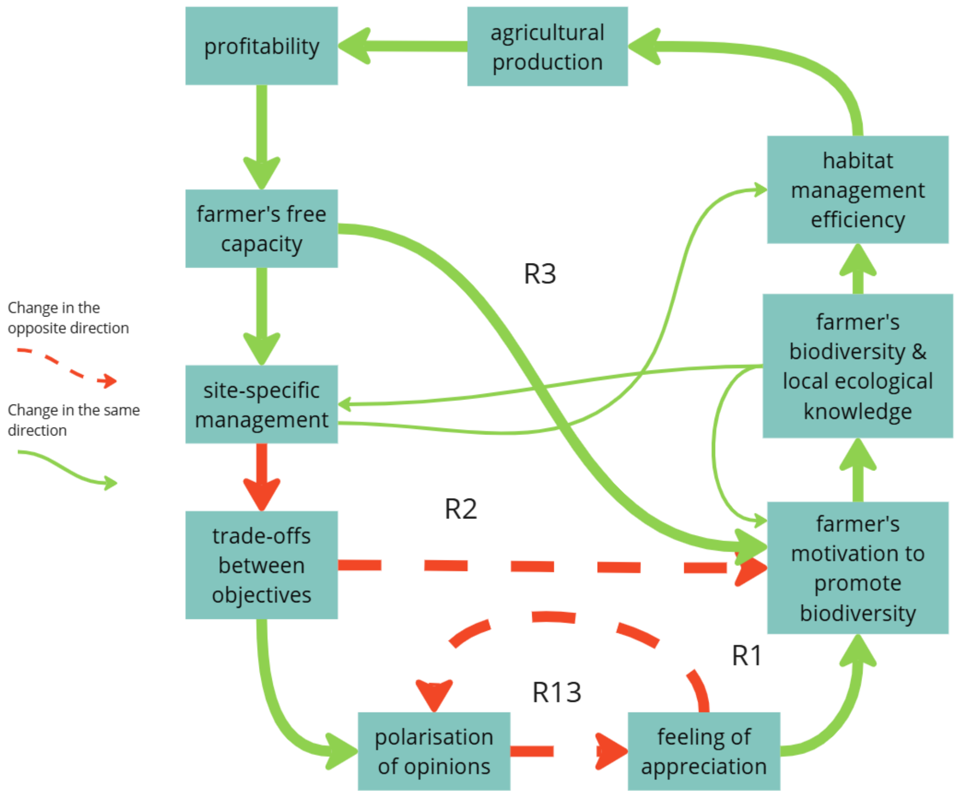

Figure 10: Impact of habitat management success on profitability

In Figure 10, R13 shows the conflict loop created by the "polarisation of opinions" between interest groups. R1 and R2 illustrate how a lack of "site-specific management" increases the trade-offs between agricultural production and biodiversity promotion. Therefore, "farmers' motivation to promote biodiversity" and knowledge acquisition are reduced. Moreover, the lack of site-specific management at the landscape level increases the trade-offs. Therefore, opinions are polarised, leaving the farmers feeling unappreciated. R3 shows how farmers are not motivated to promote biodiversity or acquire knowledge due to a lack of free capacity, for example, caused by strict regulations. Therefore, the efficiency of biodiversity promotion is reduced. Thus, "agricultural production" is reduced due to increased opportunity costs related to biodiversity promotion. Consequently, farm profitability, capacity and the motivation of farmers are reduced.

In the lock-in situation described earlier, the farmer does not engage in site-specific management (the example with R7, Figure 9). Therefore, trade-offs between agricultural production and biodiversity promotion are increased. The reinforcing feedback loops R1 and R2 in Figure 10 as well as R4 and R8 in Figure 11 illustrate how perceived trade-offs reduce farmers' motivation to promote biodiversity. In R1, the increase in "trade-offs between objectives", in addition, increases the "polarisation of opinions", activating the reinforcing "conflict loop" (R13). These feedback loops illustrate the current situation where farmers engage in biodiversity promotion as part of requirements for direct payments and, therefore, are more interested in learning about the regulations than biodiversity. R13 (Figure 10) shows how the high "polarisation of opinions" and low "feelings of appreciation" create a reinforcing loop where the conflict between farmers/farmer's representatives and advocates for biodiversity promotion is increasing.

R12 in Figure 11 shows the reinforcing loops between farmer's motivation and knowledge acquisition. A similar observation of the reinforcing effect of motivation was made by Klebl et al. (2024) between farmers' motivation and ability. Motivation seems to increase ability, while ability increases motivation. While the reinforcing mechanism in this research was more linked to the understanding of biodiversity, knowledge was also strongly linked to farmers' ability.

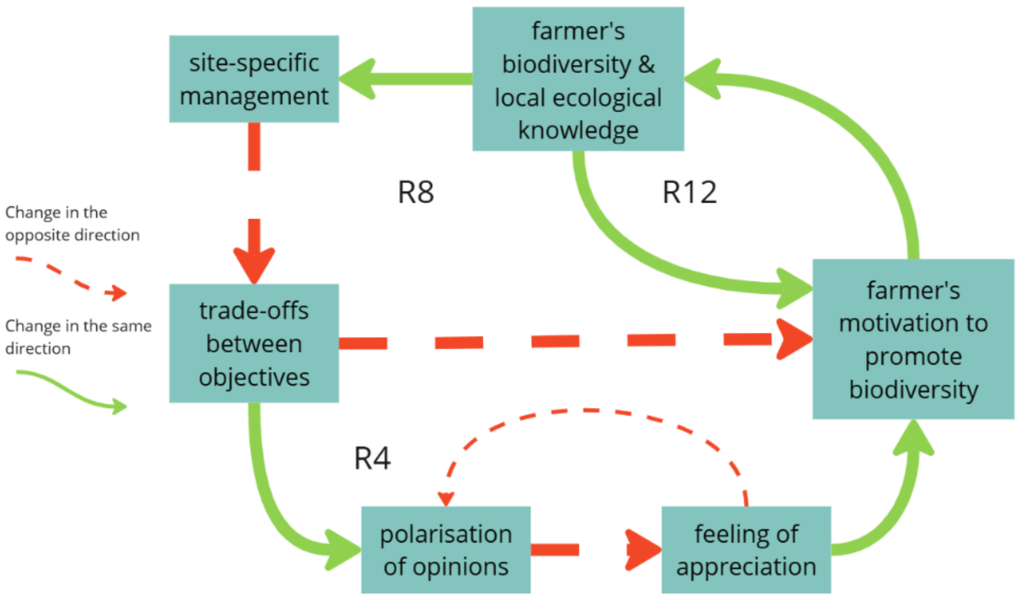

Figure 11: Impact of trade-offs between objectives

Figure 11 illustrates how the trade-offs between biodiversity promotion and agricultural production reduce farmers' motivation to promote biodiversity. The perceived trade-offs at the societal level increase the “polarisation of opinions”, creating conflicts between interest groups. As an outcome of the polarised discussion, farmers do not feel appreciation for their professional role, and their motivation to promote biodiversity reduces. Therefore, they are not interested in acquiring biodiversity-related knowledge and do not engage in site-specific management, increasing the trade-offs.

If the farmer engages in “site-specific management” directed towards “habitat management efficiency”, it creates a reinforcing loop (R5 in Figure 12) due to the positive synergies with agricultural production, increasing “farmer’s free capacity” and “site-specific management”. However, the lack of “management flexibility” in the direct payments system reduces “farmer’s free capacity” and “site-specific management”. Therefore, the lock-in mechanisms preventing improvements in habitat and ecological quality are strengthened.

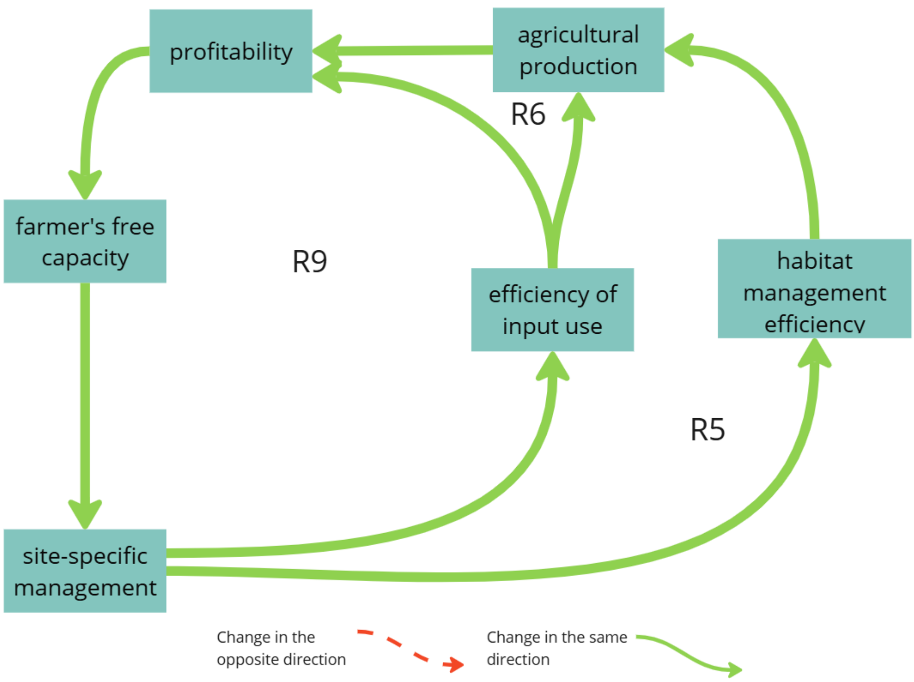

Figure 12: Benefits of site-specific management

Figure 12 shows how farmers can direct site-specific management towards agricultural production or habitat management efficiency. If it is directed towards agricultural production, it increases the “efficiency of input use”, which increases “profitability” by reducing costs and increasing production. If directed towards habitat management, “site-specific management” increases “profitability” by increasing “habitat management efficiency”.

The feedback loops R9 and R6 in Figure 12 illustrate how “site-specific management” (or the lack of it) can activate reinforcing loops for increasing (or decreasing) “agricultural production”. The interviewees recognised the need to optimise input use for the location when the goal was agricultural production. Thus, “site-specific management” aimed at “agricultural production” is assumed to increase the “efficiency of input use”, which would increase “profitability” by increasing “agricultural production” (R6) and reducing input costs (R9), creating two reinforcing loops (Figure 12) and increasing the use of site-specific methods. However, the interviews indicate a general lack of site-specific management and, thus, inefficient input use in agricultural production. Also, some farmers prioritise maximising yields higher than profitability, creating resistance to input use reduction (Bjørnåvold et al., 2022).

In conclusion, the system is currently in an unsustainable state due to the lock-in mechanism, and habitat and ecological quality continue to decrease despite governmental biodiversity regulations. The lock-in mechanisms emerge from the interplay of balancing and reinforcing loops, where demotivation, perceived trade-offs, and inefficiencies create barriers to biodiversity promotion. Addressing these lock-ins requires interventions that activate positive reinforcing loops and mitigate the constraints imposed by balancing loops.

4.4 Identification of barriers and leverage points

In this chapter, I answer the research question, “*What are the barriers and leverage points for improving habitat and ecological quality on agricultural land in Switzerland?*”. I have identified and analysed leverage points and barriers for promoting biodiversity in agricultural systems based on stakeholder insights, feedback loop and network analysis. Key findings highlight the interconnectedness of these leverage points and their role in creating systemic change. A comparative summary of the system analysis (network analysis and feedback loops) and stakeholder insights can be found in Table 6 in Appendix C: Tables.

4.4.1 Barriers and bottlenecks

The system analysis focused on network metrics such as betweenness centrality, closeness centrality, degree centrality, eigenvector centrality and the number of feedback loops. These values for each factor can be seen in Appendix C: Tables, in Table 5. These measurable relationships within the system highlight potential barriers and bottlenecks[6]. The “efficiency of input use”, “farmer’s biodiversity and local ecological knowledge”, “farmer’s motivation to promote biodiversity”, “feeling of appreciation”, and “site-specific management” are highlighted as potential bottlenecks due to high betweenness centrality and as barriers due to high closeness centrality.

[6] By bottlenecks, I mean key factors within the system, that play a critical role in connecting different parts of the system but may have limited capacity or efficiency, potentially hindering the overall system functioning.

“Farmer’s motivation to promote biodiversity” is part of most feedback loops (13/17) and has the highest in-degree (6) and betweenness centrality (101,8). However, it has a low out-degree (2) and eigenvector (0), indicating that it primarily acts as a receiver of systemic dynamics rather than a direct driver of change. “Site-specific management” is part of 10 feedback loops and has the second highest betweenness (85) and highest closeness (0,5) centrality. However, “site-specific management” has a higher out-degree (3) and eigenvector (0,4) than motivation. Therefore, it represents an actionable driver for addressing trade-offs and enhancing efficiency. “Farmer’s biodiversity and ecological knowledge”, alongside “efficiency of input use”, play significant roles in driving positive reinforcing loops. While knowledge has a strong influence due to its high closeness (0,4) centrality, efficiency impacts outcomes more directly through its higher out-degree (3) and eigenvector centrality (0,5). “Habitat management efficiency”, with its relatively high betweenness (30,6) and eigenvector (0,5) centrality, high inclusion in feedback loops (10) and very direct impact on “habitat and ecological quality”, might also act as a critical bottleneck and barrier. “Profitability”, with its relatively high betweenness centrality (33,8) and inclusion in many feedback loops (9), indicates that economic constraints are a resilient barrier to systemic change. “Obligatory protection of farmland” has a high closeness centrality (0,5) and the highest out-degree (5), indicating its role as an influential barrier. The “feeling of appreciation” has a relatively high closeness centrality (0,4) and in-degree (4), indicating that farmers’ perceptions of their societal value can act as a barrier and reflect shifts in broader systemic drivers, such as policies or public sentiment. Similarly, the “polarisation of opinions”, with its high in-degree (4), reflects societal tensions between productivity and biodiversity, signalling potential systemic volatility.

Some barriers, such as those related to motivation, knowledge, and financial aspects, are identified based on stakeholders’ statements and quantitative indicators. However, the importance of factors such as “administrative effort” and lack of “consumer demand for biodiversity labels” as barriers would have gone unnoticed without stakeholder engagement. The qualitative analysis focused on identifying states of factors that act as barriers to change. Based on the interviews and workshop, “administrative effort”, “polarisation of opinions”, “obligatory protection of farmland”, lack of “management flexibility”, and lack of consumer demand for biodiversity labels are barriers to habitat and ecological quality improvements.

While “obligatory protection of farmland” increases “habitat and ecological quality”, many interview participants perceived it as problematic. The undesired effects are reduced “management flexibility”, reduced “feeling of appreciation”, and increased “administrative effort”. “Obligatory protection of farmland” triggers 12 reinforcing loops (and three balancing) in the undesired direction. Only three are triggered in the desired direction. “Administrative effort” triggers nine loops (B and R 1, 2 and 3; R5, 6 and 9), from which six are reinforced into the undesired direction. Considering this, minimising administrative efforts while conserving management flexibility in biodiversity promotion schemes seems vital.

Lack of “management flexibility” was highlighted as a barrier in the interviews and the workshop. The impacted feedback loops are similar to the “obligatory protection of farmland” but without a positive impact on habitat and ecological quality. It was mostly discussed in the context of strict regulations related to the agricultural direct payment system, reducing farmer's motivation to do anything more than what is required and preventing them from applying their knowledge. In addition, lack of management flexibility reduces farmer’s biodiversity knowledge acquisition, as they cannot apply their knowledge.

The lack of “consumer demand for sustainability labels” was indicated by two farmers (nr. 1 and 3), one in the interview and one in the validation. Due to the lack of consumers' willingness to pay for biodiversity promotion, the financial incentives for biodiversity promotion are low. Thus, the financial incentives need to come from governmental support. Lack of consumer demand triggers all feedback loops into an undesired direction through the reduced compensation for biodiversity promotion. Yet, one participant (Stakeholder nr 3) in the workshop mentioned that the markets are changing and could act as a leverage point. Also, T. G. Williams et al. (2024) found that Switzerland has a high potential for alternative food networks, creating possibilities for sustainability transformations of the agri-food system.

While “agro-industrial value chains” were not mentioned directly by the participants, a high focus on food production, typical of actors in agro-industrial value chains (T. G. Williams et al., 2024), was discussed often. The focus on food production was also perceived to increase the trade-offs between objectives and the polarisation of opinions. In the scientific literature, multiple lock-ins related to agro-industrial value chains are identified in Chapter 2. T. G. Williams et al. (2024) found that “agro-industrial control” related to agro-industrial value chains is medium-high in Switzerland. Furthermore, productivist attitudes and agricultural intensification related to agro-industrial control were highlighted as drivers for landscape simplification and reduction in habitat and ecological quality, (Estrada-Carmona et al., 2022; Stoate et al., 2001; Tscharntke et al., 2005; Van Vliet et al., 2015). Also, one participant mentioned the simplification of landscapes due to increased field size (stakeholder nr.1). High farm specialisation related to agro-industrial value chains also acts as a barrier to participating in agri-environmental schemes (Canessa et al., 2024; Klebl et al., 2024). Therefore, “agro-industrial value chains” are creating undesired changes in two ways: by increasing the “polarisation of opinions” and by reducing “landscape complexity” and, therefore, “habitat and ecological quality”.

In summary, the barriers prioritised based on the stakeholder insights and scientific literature are “obligatory protection of farmland”, *“*administrative effort*”*, lack of “management flexibility”, lack of “consumer demand for biodiversity labels”, “trade-offs between objectives”, “polarisation of opinions” and “agro-industrial value chains”. “Farmer’s free capacity”, “biodiversity and local ecological knowledge”, and “motivation to promote biodiversity” affected by these barriers act as critical bottlenecks in the system.

4.4.2 Leverage points

“Farmer's free capacity”, “site-specific management”, “efficiency of input use”, and “financial compensation for biodiversity promotion” were highlighted as potential leverage points based on the system analysis. “Farmer’s free capacity”, “site-specific management”, and “efficiency of input use” have a combination of high or relatively high out-degree, eigenvector centrality and inclusion on feedback loops. “Financial compensation for biodiversity promotion” is not included in feedback loops but has relatively high out-degree and eigenvector centrality.

The following factors were identified as leverage points in the participatory mapping workshop:

- Farmer’s biodiversity and local ecological knowledge and acknowledgement of it
- Farmer's free capacity
- A feeling of being appreciated and trust
- Financial compensation for biodiversity promotion
- Farm-tailored advice and training with a goal

The system analysis gave different results than the stakeholders' identification of leverage points. Stakeholders identified only farmers’ knowledge, free capacity and financial compensation as leverage points, whereas “site-specific management” and “input use efficiency” were ignored. On the other hand, not all factors identified by the stakeholders as leverage points have high out-degree, eigenvector or inclusion in feedback loops. However, “farmer’s biodiversity and local ecological knowledge” and “feeling of appreciation” were identified as potential bottlenecks or barriers due to their betweenness and closeness values and inclusion in feedback loops.

“Farmer’s free capacity” was seen in the workshop as an essential factor for farmers to experiment: *“We had an exciting workshop where we discussed an experimental budget. Is it really an opportunity for farmers to experiment and try out new things.”* (Stakeholder nr. 2, workshop). Based on the network analysis, “farmer's free capacity” is the most central and influential factor in the network, as enhancing farmers’ time, resources, and flexibility has the potential to influence other key factors. It has the highest eigenvector (1,0), relatively high betweenness (51,1), and in-degree (3) centrality, and it is part of nine feedback loops. Capacity is also part of the three reinforcing loops visible in Figure 13. All the feedback loops are shared with “profitability”, indicating the strong dependency of capacity on it. Eight of these are also shared with “agricultural production”, and seven with “habitat management efficiency”. Capacity is included in six reinforcing loops, of which it shares three with knowledge (R1, R2, R3 in Figure 13). Perhaps more interestingly, capacity is included in three balancing feedback loops (B1, B2, B3 in Figure 8), possibly making it an important factor in overcoming lock-ins. It could act as a buffer to prevent the feedback loops from activating, allowing the desired direction of reinforcing loops to become dominant.

As mentioned in connection with the feedback loops in Chapter 4.3, “farmer's biodiversity and local ecological knowledge”, is part of eight feedback loops. Moreover, it has high betweenness centrality and out-degree centrality. All the feedback loops knowledge is part of are reinforcing, highlighting its potential for change. Three examples, R1, R2 and R3, are illustrated in Figure 13. All of them could be considered examples of successful habitat management, where benefits for agricultural production are maximised, and the farmer experiences joy from biodiversity promotion. Increasing knowledge was seen as a means of increasing farmers' motivation to promote biodiversity. Knowledge shares the most feedback loops with motivation (8), indicating its high impact on it. Also, five of the feedback loops are shared with “habitat management efficiency”. Furthermore, five of the reinforcing feedback loops triggered by knowledge are also connected to “site-specific management”. Also, acknowledging farmers’ knowledge and allowing them the freedom to apply it was highlighted in the workshop. One farmer stated that ZiBiF, as a goal-oriented scheme, increased the acknowledgement of farmers' knowledge:

> *“The fact that we are taken seriously in this project, that we can make our own suggestions and that we have freedom in the design of the habitats, and we are rewarded according to quality.” (Farmer nr. 5)*

I interpreted the acknowledgement and freedom to apply knowledge as a condition for the connection between “farmer’s biodiversity and local ecological knowledge” and “habitat management efficiency” and between knowledge and “site-specific management”. Thus, if the farmer’s knowledge is not acknowledged, six reinforcing loops (R1, R2, R4, R7, R8, R10) cannot be activated in the desired direction. This would cripple the potential for the desired change in the system.

Despite being selected as a leverage point, the “feeling of appreciation” is only part of four feedback loops. However, it is highlighted as a potential barrier and indicator of system volatility. Furthermore, I suspect that its impact was not sufficiently mapped. For example, the potential impact on cooperation mentioned by one research participant is not included in the CLD. In any case, the “feeling of appreciation” is included in three reinforcing loops (Figure 13) and one balancing loop (B1 in Figure 8). Two reinforcing loops are shared with knowledge (R1 and R2) and one with capacity (R1). The third one is R13 (conflict loop), formed with “polarisation of opinions”.

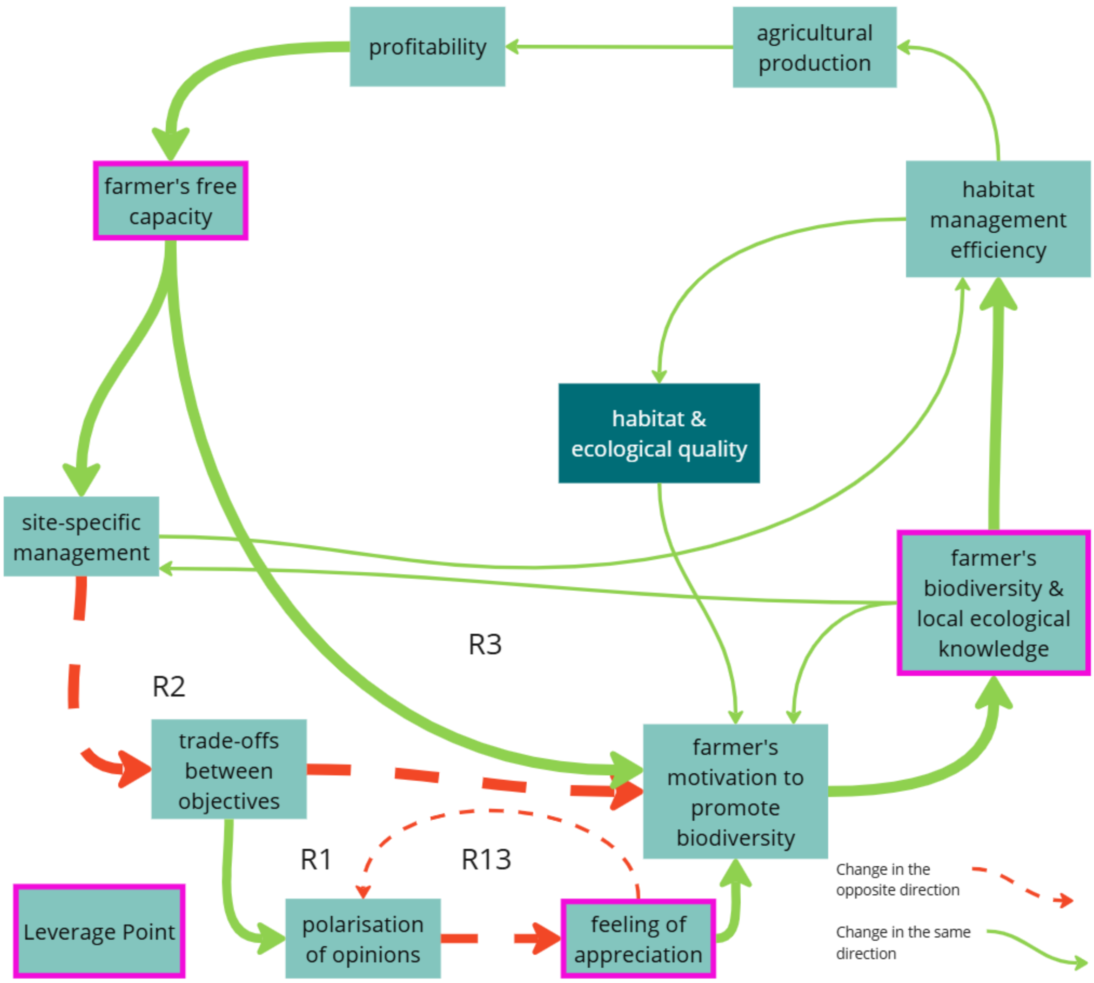

Figure 13: Example feedback loops with leverage-points

Figure 13 shows four examples of reinforcing feedback loops the leverage points activate. Increasing knowledge could lead to successful habitat management, activating R1, R2 and R3. Increasing the “farmer's free capacity” would allow the farmer to experiment. Increasing the free capacity could lead to more efficient site-specific and habitat management and activating feedback loops R1, R2, and R3. Increasing the “feeling of appreciation” further reduces the “polarisation of opinions” and increases “farmer's motivation to promote biodiversity”, activating R1.

The last two leverage points, “farm-tailored advice and training” and “financial compensation for biodiversity promotion”, can be seen in Figure 14. They are not part of feedback loops. Therefore, I analysed their potential impact based on which feedback loops they trigger through the connections to factors that are part of feedback loops.

While identified by stakeholders, “farm-tailored advice and training” does not stand out as an important factor based on the system analysis. Even so, “farm-tailored advice and training” activate 12 feedback loops, including all four balancing loops and eight reinforcing loops. The feedback loops are activated through the connection to the leverage points “farmer’s biodiversity and local ecological knowledge” (ten loops) and “feeling of appreciation” (four loops). Loops R1 and B1 are activated by both factors. For example, all four reinforcing loops in Figure 10 are activated by “farm-tailored advice and training”, creating desired reinforcing effects through successful habitat management and increased motivation for farmers to promote biodiversity.

“Financial compensation for biodiversity promotion” has the highest out-degree (4) of all the leverage points. Through its connections to “profitability”, “farmer's motivation to promote biodiversity”, and a “feeling of appreciation”, all the feedback loops (4 balancing and 13 reinforcing) in the CLD are activated in the desired direction. However, financial compensation increases “administrative effort” and reduces “management flexibility”. Therefore, ten reinforcing loops activate in the undesired direction. Network analysis does not consider the polarity of connections, resulting in misinterpretation if used for leverage point identification (Crielaard et al., 2023). Nevertheless, compensating for biodiversity seems vital for efficient habitat management, as pointed out in the interviews and the workshop. Most current compensation systems were perceived as insufficient, considering the time and effort farmers are expected to invest. While compensation is a key motivator for farmers to participate in biodiversity promotion schemes, other motivators exist. Some farmers are willing to engage in biodiversity promotion without governmental compensation (e.g. farmer nr. 2) (Tyllianakis & Martin-Ortega, 2021). The benefits of ZiBiF as a goal-oriented intervention (hybrid result-oriented), were highlighted. However, result-based schemes might be less effective in changing practices (Fleury et al., 2015), thus causing a potential lack of additionality (Canessa et al., 2023). The question of additionality in the ZiBiF project is discussed in Box 6 in Appendix B: Research memos. In any case, increasing financial compensation promotes the participation of farmers, who otherwise might not have been motivated to promote biodiversity (Wang et al., 2023).

In conclusion, the leverage points identified by research participants show potential for shifting the system towards the desired direction. The factors “farmer’s biodiversity and local ecological knowledge” and “farmer’s free capacity” were identified earlier as bottlenecks for biodiversity promotion, and therefore, increasing them seems vital. “Financial compensation for biodiversity promotion” increases “farmer’s free capacity” and “motivation to promote biodiversity”. Assuming the farmer has sufficient free capacity, “farm-tailored advice and training” increases “farmer’s biodiversity and local ecological knowledge” and “feeling of appreciation”. However, the workshop participants ignored the potential of increasing “site-specific management” and “efficiency of input use”.

4.4.3 Interactions between barriers and leverage points

Previous studies emphasise the importance of farmer motivation as a key driver of biodiversity-friendly practices (Klebl et al., 2024). Motivation has been linked to external incentives, societal recognition, and the perceived benefits of biodiversity promotion. My findings highlight that while motivation may be a bottleneck for biodiversity promotion, it is not an effective leverage point. That said, the findings show that knowledge shares many feedback loops with motivation, confirming the mutual reinforcement between these two factors. Scientific literature also highlights the central role of farmers’ biodiversity and ecological knowledge in fostering site-specific management and improving habitat quality (Duru et al., 2015). Knowledge enhances the adoption of biodiversity-friendly practices by increasing farmers’ understanding of ecosystems and enabling them to implement effective solutions. Indeed, knowledge and understanding of biodiversity, ecosystems and environmental problems increase adaptation of biodiversity-friendly measures (Klebl et al., 2024). This underscores that increasing knowledge directly strengthens motivation, a key finding supported by stakeholder perceptions.

Fleury et al. (2015) discovered that French farmers appreciated the freedom of result-based biodiversity promotion to implement practices that can be adapted to the year and their needs and perceived result-oriented payments as a way to better recognise their knowledge and skills. My study highlights how acknowledgement and freedom to apply knowledge are critical for its effective use. This finding adds to the discussion about farmer autonomy in biodiversity promotion. As expressed by the participants of this research, Mack et al. (2020) also found that farmers’ knowledge is significantly more critical in Swiss result- and connectivity-based biodiversity schemes compared to action-based schemes. In Germany, the mandatory late mowing date, which does not allow adaptation to changing weather conditions, was similarly criticised (Canessa et al., 2023). Also, Kuokkanen et al. (2017) conclude that in the context of Finnish agri-environmental schemes, their inflexibility is not fit to deal with the complexities of ecological systems and undermines farmers' knowledge.

Lack of “management flexibility” and increased “administrative effort”, as well as “obligatory protection of farmland”, which impacts the first two, were identified as barriers in this research. They limit the application of farmer’s knowledge and site-specific management through the enforcement of top-down rules. Similarly, Karali et al. (2014) found that administrative effort and management restrictions act as barriers to the adaptation of biodiversity schemes for Swiss farmers. Linares Quero et al. (2022) indicate similar findings related to the Common Agricultural Policy of Europe. The rules related to direct payments are considered too complex and bureaucratic and do not have the space for dialogue between authorities and farmers. Thus, the benefits of farmers’ local knowledge and changing conditions cannot be accounted for. Likewise, Klebl et al. (2024) identified a lack of management flexibility as a barrier, as increased flexibility generally increases farmers’ participation in biodiversity promotion schemes. Hence, for knowledge to act as a leverage point, these barriers need to be removed.

While “site-specific management” and “landscape complexity” were not highlighted as leverage points, the need for landscape-scale approaches and site-specific management has been widely recognised as an effective strategy for balancing biodiversity and agricultural production goals (Tscharntke et al., 2012). It reduces trade-offs by tailoring interventions to local conditions, maximising both ecological and economic benefits. Scientific literature shows that food production and biodiversity promotion at the landscape level might not conflict (Zingg et al., 2018) and may have benefits such as pollination, biological pest control and nutrient recycling (Tscharntke et al., 2005). Like the points highlighted by the participants in this research, the scientific recommendations are to conserve rare and endangered species in areas where biodiversity is still high and to promote functional biodiversity in intensively managed landscapes where the benefits from ecosystem services are larger. Biodiversity is typically higher in areas with lower agricultural potential. These are the areas in which agricultural intensification has not impacted biodiversity as strongly yet. Efficient integrated landscape management would minimise the trade-offs between food production and biodiversity promotion (Estrada-Carmona et al., 2022; Tscharntke et al., 2021). Additionally, farmers located in areas with unfavourable conditions for agricultural production have a greater willingness to participate in biodiversity conservation schemes (Klebl et al., 2024).

However, individual farmers do not have the power to engage in landscape-scale strategic management (Busse et al., 2021); thus, the effects of site-specific management remain limited. Moreover, in the current economic paradigm, farmers are not incentivised to implement practices related to site-specific management, such as ecological intensification (Kleijn et al., 2019; Stoate et al., 2001). While the majority of scientists and farmers both have positive attitudes towards biodiversity promotion, scientists tend to consider ecosystem services more important for agricultural production than farmers (Maas et al., 2021). Farmers understanding of the trade-offs and benefits of adopting biodiversity schemes is limited (Canessa et al., 2024). Scientists, in turn, might hold idealistic values, overestimating the benefits of conservation measures for agricultural production (Maas et al., 2021).

The findings confirm the importance of selecting goals and management practices based on the area's potential. Related to this, site-specific management has high inclusion in multiple feedback loops and high centrality values. My study highlights that knowledge and management flexibility are prerequisites and enablers for successful site-specific management. However, for example, Klejin et al. (2019) recommend more regulatory instruments with compulsory practices to increase ecological intensification. Controversially, based on the barriers and leverage points identified in this study, my recommendation would be to empower farmers with knowledge and management flexibility in biodiversity schemes and increase cooperation on the landscape level. Even so, the workshop participants did not completely undermine the necessity for top-down environmental regulations.

Previous studies have identified financial and time constraints as barriers to farmers' motivation to promote biodiversity (Wilson & Hart, 2000). For example, a study regarding the reduction of pesticide use in French farmers mentioned that they lacked the necessary knowledge and experience. Others stated that due to the increased workload, they needed time to adjust (Bjørnåvold et al., 2022). Karali et al. (2014) found that insufficient support for innovation was one of the most often mentioned barriers in Switzerland for farmers to participate in agri-environmental schemes. While the workshop participants wanted a positive relationship between efficient biodiversity promotion and agricultural production, the benefits assumed in the causality do not seem sufficient to increase farmers' motivation for biodiversity promotion. This might be because intensive input use likely still has higher profits for the farmers under the current economic paradigm (Kleijn et al., 2019). My findings show that “farmer’s free capacity” is part of both balancing and reinforcing loops, indicating its dual role as a systemic buffer and enabler of experimentation. Therefore, interventions to increase capacity in combination with motivating farmers to promote biodiversity could tip the system toward desirable biodiversity outcomes.

Increased “polarisation of opinions” and lack of “feeling of appreciation” were indicated as a barrier to “farmers’ motivation to promote biodiversity” and cooperation. The discussion highlighted the impact of choosing extensive farming on farmers' reputations, the pressure to produce food and the feeling of being blamed for environmental issues as a barrier to biodiversity promotion. For example, the perceived negative attitudes towards organic farming in Switzerland hinder its adaptation (Home et al., 2019). Karali et al. (2014) found that social image was perceived even more important than profitability when Swiss farmers considered applying environmentally friendly practices. Also, Klebl et al. (2024) highlighted the importance of reputation and its impact on the farmers' social capital as an important factor. Besides, environmental discussions in the media create feelings that farmers' professional identities are attacked and increase the lack of understanding between farmers and non-farmers, leading farmers to take a defensive standing (Bjørnåvold et al., 2022). Thus, the reduced “feeling of appreciation” caused by the “polarisation of opinions” will act as a barrier to “farmers' motivation to promote biodiversity”. One reason for the failure of Swiss agri-environmental schemes could be resistance from the relatively powerful Swiss farmers’ unions (Mann & Kaiser, 2023). Lécuyer et al. (2021) suspect that farmers will continue to experience increasing conflicting pressures from market and conservation drivers created by the diverse worldviews of different actors. Tackling the trends leading to the polarisation of opinions and increasing dialogue and cooperation between interest groups seems vital for successful biodiversity promotion.

Reflecting on the leverage points based on Meadows’ (1999) classification (see Figure 4, p. 20), increasing financial compensation, advice, free capacity and knowledge are shallow leverage points, while increasing the feeling of appreciation is a deep leverage point. I identify “financial compensation for biodiversity promotion” and “farm-tailored advice and training” as parameter-level leverage points. Changing them alone might not bring any long-term change in the system, as the farmers will not be able or motivated to benefit from them without increased capacity and a feeling of appreciation. Increasing the “farmer’s free capacity” would increase the buffer, also making it a parameter-level intervention. “Farmer’s biodiversity and local ecological knowledge” on its own might be a parameter-level leverage point, but acknowledging farmer’s knowledge strengthens positive feedback loops. Thus, it is a feedback-level leverage point. Interventions addressing the “conflict loop” (polarisation of opinions” and “feeling of appreciation”) would likely have to influence the underpinning values, goals and worldviews of actors, making it an intent-level leverage point. For example, Lécuyer et al. (2021) suggests that recognising farmers and local actors rather as part of the solution and not the problem, would increase respect and facilitate equal partnership.

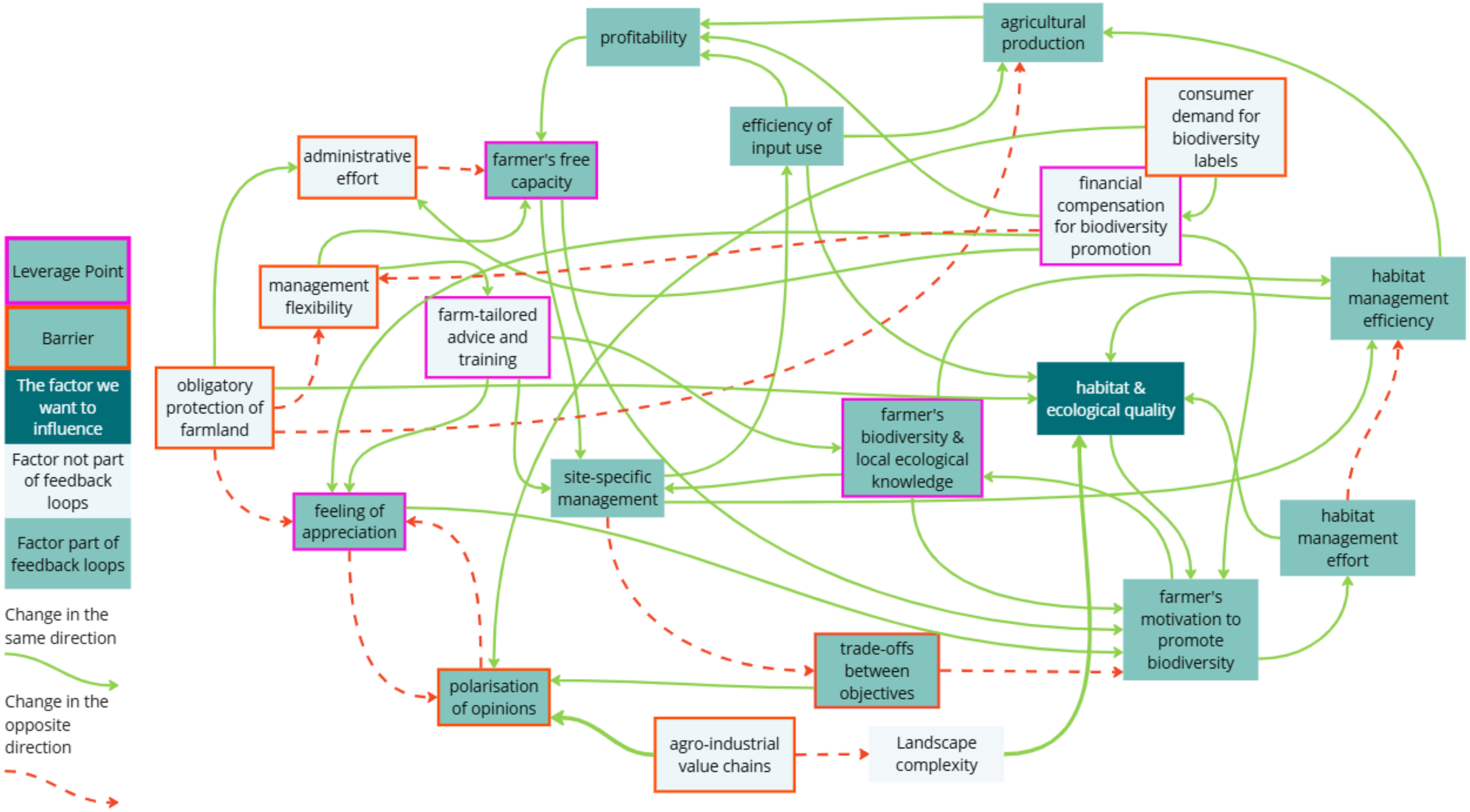

Figure 14: CLD with key factors for habitat and ecological quality in agriculture

The findings of this study emphasise the complex interplay between barriers and leverage points in promoting biodiversity-friendly agricultural practices. As highlighted in Chapter 4.4, systemic barriers such as economic constraints, "administrative effort", and lack of "management flexibility" interact with critical leverage points, including "farmer's free capacity", "site-specific management", and "farmer's biodiversity and local ecological knowledge". These interactions shape the dynamics of motivation, cooperation, and the adoption of biodiversity schemes. While barriers like "obligatory protection of farmland" and "administrative effort" constrain the flexibility and, therefore, application of farmer knowledge. Enabling factors such as "farm-tailored advice and training", "financial compensation for biodiversity promotion", and "feeling of appreciation" have the potential to unlock systemic transformation. The high centrality of "site-specific management" and its inclusion in multiple feedback loops further underscores its potential to bridge agricultural productivity with biodiversity goals, provided that enabling conditions such as management flexibility and sufficient knowledge are met. Ultimately, reducing bureaucratic complexity and addressing the polarisation of opinions are necessary steps to shift the system.

4.5 Transition pathways towards biodiversity-friendly agricultural system

The research question "*Which transformation pathways do the stakeholders envision for a biodiversity-friendly agricultural system in Switzerland?"* is answered in this chapter. I explore pathways envisioned by the research participants for the sustainability transformation of the Swiss agricultural system for biodiversity promotion. Drawing on insights from workshops, interviews, and scientific literature, the chapter examines key interventions. Special attention is given to the role of farmer inclusion, clear goals, and tailored interventions in fostering a sense of ownership and motivation among farmers. This chapter integrates these insights within a ToC (Figure 15), nested in the CLD (Figure 14). The ToC outlines pathways to enhance habitat management efforts and efficiency, as well as provides a visualisation of the dynamic interplay of interventions and leverage points highlighted by the stakeholders. At the end of the chapter, acknowledging the barriers and lock-ins not addressed by the interventions emphasises the need for a holistic and collaborative approach to biodiversity promotion in Switzerland.

4.5.1 Goal of biodiversity conservation on agricultural land

The leverage points and interventions were primarily identified in only one of the groups at the workshop. In the second group, participants had a deeper discussion regarding the goals of biodiversity promotion in Switzerland. They ended up with an agreement that there is a need for more dialogue about the goals and farmers need to be acknowledged and included more:

“I think it's important to consider this polarisation of opinions and to try to work on it because I've noticed that recently, in this vote (biodiversity initiative; see Reuters (2024)) and in general, we don't actually discuss the matter anymore or it is no longer at the factual level, the way it is done, and we should try to promote this mutual understanding again because what you hear in the media is not what you then experience 1 to 1. What occurred to me just now is that we are always talking about agricultural production and biodiversity, but biodiversity is also connected with the overall protection of resources: soil, water, air, and climate. We should try to look at the big picture and somehow promote this discussion, but it's just very complex and very difficult.” (Advisor nr. 2)

“Yes, but I see exactly that you see the important point that you have to break this down, that you have to look at the big picture, and then it is clearer what the goals are. I think that if a farmer has clear goals and is involved in the big picture, then they don't need to look around so much.” (Farmer nr. 3)

Canessa et al. (2024) found that variables affecting scheme alignment with farmers’ attitudes and operations have a significant impact on adaptation. Fleury et al. (2015) concluded that in their case study about result-based biodiversity payments in France, long-term discussions between agricultural and environmental stakeholders regarding biodiversity promotion of farmland and its role in agricultural production and quality were necessary for the success of the scheme. For example, Lécuyer et al. (2021) call for the adaptation of structured partnership approaches involving a variety of actors and the development of early conflict reconciliation plans, while Maas et al. (2021) point out the need for dialogues between key agricultural stakeholders and scientists. Biodiversity promotion schemes are more likely to be adapted to the local conditions and farming practices if farmers are included in the decision-making, and tailoring schemes to the context increase farmer’s participation (Klebl et al., 2024).

After the two groups shared the changes in the CLD and leverage points with each other, many (3/5) in the second group expressed that they highly agreed with the points brought out by the first group:

“From my perspective as a farmer, we can take the system map of group 1, which corresponds 100% to my experience as a soon-to-be-retired farmer. We farmers would like to be taken seriously, and we would like to be involved in the development of systems.” (Farmer nr. 5, workshop)

In summary, the participants had different perspectives on the desired goal of biodiversity conservation. The workshop participants recognised a need for more dialogue about biodiversity goals and the inclusion of farmers in decision-making. The group with less diverse perspectives had the time to discuss potential leverage points and interventions, while the other group needed more time to establish a common ground.

4.5.2 Theory of change and transition pathways

I have mapped the causal path from the interventions to the goal of improved habitat management in the ToC shown in Figure 15. The interventions and their potential impact were identified in the participatory mapping workshop. Four of the interventions were identified in the workshop, and I identified three based on their importance in the interviews and scientific literature.

Six interventions were discussed in the workshop in relation to the leverage points identified earlier:

- Financial compensation for biodiversity promotion
- Economic support for experimentation
- Basic education in biodiversity
- Practical training programs in biodiversity promotion/ecology
- Farm-tailored advice and training with a goal

In the workshop, the participants wanted to change the word from incentive to compensation to highlight the importance of genuinely compensating farmers for all the time and effort spent in biodiversity promotion schemes:

> *"We are compensated for area management, but the participation requires so many hours on the project, and that is rarely paid." (Advisor nr. 4, who is also a farmer)*

The improvement of economic conditions of farmers was described as follows:

> *"To really just invite farmers to use their knowledge that they have everything to create space, to apply that to biodiversity and habitats for our policies on their farms, where sometimes there is just not enough time. To do that, you have to fill out projects, applications, and so on all the time. So that you can provide support with no strings attached, so really no conditionalities." (Stakeholder nr. 3)*

The lack of biodiversity in agricultural education was recognised in the workshop:

> *"Because it is a part that is currently very marginal because it is simply not needed in the direct payment system. But, of course, there would be a great deal of leverage there." (Stakeholder nr. 1)*

The importance of practical aspects in the education and training were highlighted:

> *"This training must somehow not be theory because what you hear from what is now in schools is that they have nothing to do with it; it must also be practice-oriented or based on local conditions." (Advisor nr. 4)*

"Farm-tailored advice and training" with a goal were highlighted in the interviews and served as leverage point and intervention:

> *“The farm-tailored advice, so I would also call that whole-farm advice. We have had very good experiences with this in a project, which is exactly not just about ecological but also about economic goals.” (Stakeholders nr. 5)*

Also, Klebl et al. (2024, p. 852) emphasised the need for advice tailored to the regional context (e.g. species, structures, geophysical conditions, landscape dynamics) farming system and accounts for the farmer's attributes (e.g. knowledge, skills, attitudes, motivations and abilities). While farmers and non-farmers in this research mentioned both farm-tailored advice and training and learning from peers, Fleury et al. (2015) found in their study that farmers perceived discussions with peers and group visits to explore techniques other farmers have implemented as especially important. The interventions targeting farmer’s biodiversity and ecological knowledge can have beneficial effects by raising awareness about environmental issues and benefits for biodiversity promotion, increasing peer support and reducing the feeling of being alone. However, price can act as an access barrier to these services, and the provisioning of publicly funded services depends on political support (Linares Quero et al., 2022). The current institutional capacity might not be sufficient to provide enough advisory services (Šumrada et al., 2021), and the polarised opinions might prevent such large institutional investments.

In addition, I added two more interventions identified based on their importance in the interviews, confirmed with the scientific literature:

- Landscape approach for biodiversity promotion
- Quality-based compensation

The landscape approach for biodiversity promotion refers to a planning process aiming at optimising land use for different goals at the landscape level, for example, by identifying where high biodiversity should be conserved and where functional biodiversity should be promoted. The importance of the landscape approach for biodiversity promotion was highlighted in interviews and the scientific literature and discussed earlier in connection to site-specific management (e.g. in Chapter 4.4.3). Navigating trade-offs at the landscape level could help to reduce conflicts resulting from different stakeholders' worldviews and goals. Implementation would require farmers to collaborate at landscape scales and develop frameworks that identify and balance land-sparing and sharing strategies. Incentive systems for higher habitat and ecological quality (such as ZiBiF) or creating habitat corridors and shared management of pollinator strips (Lécuyer et al., 2021; Tscharntke et al., 2005) could, for example, help to increase landscape complexity.

Quality-based compensation (referring to the compensation system applied in ZiBiF) was highlighted as an effective motivator for farmers to increase habitat and ecological quality in the interviews:

> *"If they just pay for quality, it doesn't matter how you get the quality, and the price for really high quality is high, then it's like a crop. So, it's like the 'crop biodiversity'. And farmers start talking with the neighbour and asking, like, what have you done with this grass? It looks pretty. How did you get there? So, then we would make a lot for biodiversity because many farmers would start to put effort into getting better quality." (Farmer nr. 1)*

The goal-oriented compensation system was mentioned generally to increase knowledge sharing and peer support among the participating farmers. Similarly, Fleury et al. (2015) highlighted the importance of providing payments for different biodiversity levels, with higher payments for higher biodiversity. Rewarding farmers for reaching goals can create a sense of responsibility and pride for one's biodiversity achievements, simulating intrinsic motivation and commitment (Klebl et al., 2024). However, scaling the goal-oriented biodiversity promotion approach would likely demand strengthening the institutional capacity to ensure the availability of advisory services (Canessa et al., 2023; Šumrada et al., 2021). Increasing the availability of context-tailored approaches by combining action- and result-oriented payments might increase the efficiency of biodiversity promotion (Canessa et al., 2023).

Compared to the CLD, the ToC diagram (Figure 15) has three more connections, which apply only when the compensation system is changed to reward farmers for higher quality and based on increased landscape complexity (e.g. connectivity payments). One connection is added from "habitat and ecological quality" back to "financial compensation for biodiversity promotion". The new connection creates multiple new reinforcing feedback loops in the desired direction. When the landscape approach to biodiversity promotion is added as an intervention, a path from "financial compensation for biodiversity promotion" through "site-specific management" and "landscape complexity" to "habitat and management quality" is created.

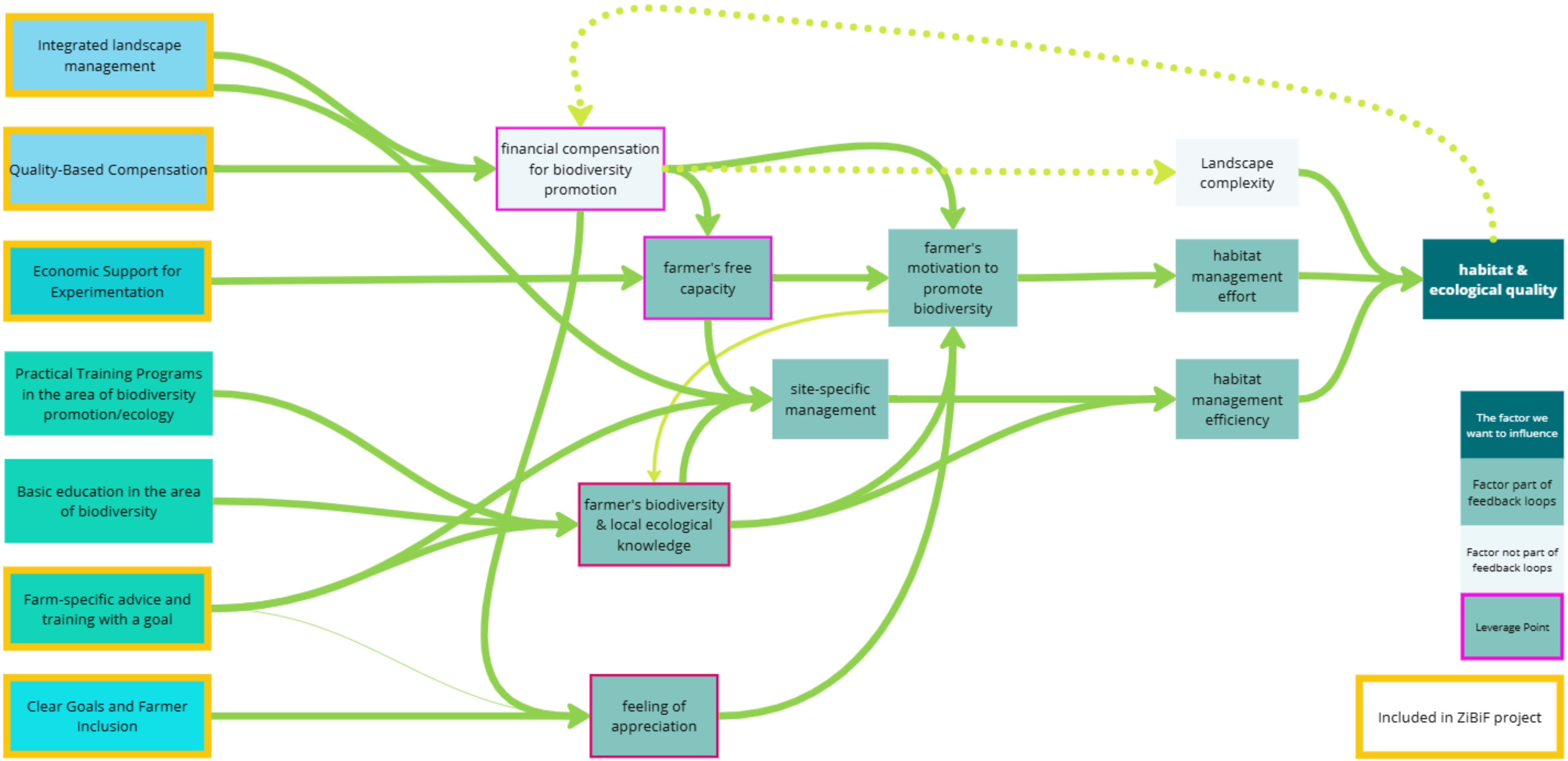

Figure 15: ToC Diagram for improving habitat and ecological quality on agricultural land

The impact of the interventions can be categorised into two groups: ones targeting farmers' knowledge and ones targeting farmers' free capacity. Landscape approach for biodiversity promotion, quality-based compensation, and economic support for experimentation increase farmers' free capacity, increasing "farmer's motivation to promote biodiversity". Therefore, farmers' "habitat management effort" is especially increased. Changing to an incentive structure that allows farmers more management flexibility, rewards farmers for results, or specific beneficial spatial positions (landscape-level approach) would change the system's rules. For this reason, they are design-level interventions that trigger deeper-level leverage points. Practical training programs in biodiversity promotion/ecology, basic education in biodiversity, and "farm-tailored advice and training" most importantly increase "farmers' biodiversity and ecological knowledge" and, therefore, farmers' "habitat management efficiency". As I argued earlier, increasing knowledge is a shallow leverage point. Leverage points related to knowledge are very common in scientific literature and may represent "*natural bias in science.*" (Dorninger et al., 2020, p. 7). Moreover, financial compensation and farm-tailored advice increase the "feeling of appreciation", increasing farmers' motivation. I argue that for the government to provide sufficient resources for financial compensation and farm-tailored advice, the intent of the agricultural system would have to change first. The increase in farmers' "feeling of appreciation" when they promote biodiversity would signal the shift in broader systemic drivers.

However, not all aspects of agri-food systems are considered. Although the need for reducing animal-based products was mentioned by two interview participants (Advisor nr. 3 and Stakeholder nr. 1), change in consumption patterns was not mentioned in the workshop. For example, Manna and Kaiser (2023) argue that reducing the consumption of animal products and food waste might be more successful than trying to further extensify Swiss agriculture. Further extensifying would lead to lower food security, which faces strong opposition in Switzerland. Notably, intensive animal husbandry is driving biodiversity loss (Gattlen et al., 2017; Stoate et al., 2001; Van Vliet et al., 2015). However, the pressure to reduce animal products might also have unexpected negative influences on biodiversity, as grassland and livestock farms have the highest adaptation of environmentally friendly measures compared to other farm types. Farms engaging in vegetable and permanent crop cultivation, on the other hand, have low adoption rates (Klebl et al., 2024). While higher livestock densities have a negative impact on farmland biodiversity (Stoate et al., 2001), the integration of livestock is vital for many extensive traditional agricultural systems important for biodiversity (Estrada-Carmona et al., 2022). Nevertheless, at least on a global scale, dietary changes are necessary if we want to simultaneously promote biodiversity-friendly farming without increasing the area dedicated to agriculture (Benton et al., 2021)

Moreover, some barriers are not addressed by the interventions. The risk of obligatory protection remains for farmers who increase habitat and ecological quality on their farmland. Furthermore, consumer demand and willingness to pay for additional efforts farmers see for biodiversity promotion is not addressed. The workshop participants highlighted the general need to increase the financial compensation for biodiversity promotion. For farmers to be motivated by financial compensation, it needs to be higher than the expected opportunity cost (Herzon et al., 2018; Klebl et al., 2024). To overcome cognitive lock-ins that reproduce the status quo, compensations need to fix the "incentive misalignment trap" created by conflicting normative environmental goals and market demand (Weituschat et al., 2022). An increase in market-based incentives simultaneously to governmental compensation might be necessary. For instance, the price of external inputs is expected to rise, while societal acceptance of the externalised environmental cost related to them is reducing, and demand for sustainably produced food might increase (Kleijn et al., 2019). Especially Switzerland has a high potential for alternative food networks, reducing the lock-ins related to agro-industrial value chains (T. G. Williams et al., 2024). The lack of concern of the research participants for barriers and lock-ins created by markets and value chains might be because the participating farmers are part of labelling schemes (organic or ÖLN), representing "multifunctional value chains".

Aspects related to value chains, market access (Linares Quero et al., 2022; T. G. Williams et al., 2024) and consumer habits (Mann & Kaiser, 2023) are not addressed, even if they are identified in the scientific literature as major barriers. Agro-industrial value chains still dominate in Switzerland, polarising opinions away from biodiversity promotion and pressuring farmers to produce more intensively. The participants of this research perceived the lock-in as preventing fruitful collaborations between stakeholders, leading to a lack of improvements in the agricultural policies for biodiversity promotion. For example, the interview participants often referred to the "biodiversity initiative" rejected in September 2024. The initiative aimed at enhancing the protection of natural habitats, including a proposal to designate three percent of arable land for conservation purposes. The main farming lobby perceived the initiative as too extreme and to pose a risk to business development. While the initiative initially had public support, after active campaigning against it, its popularity was reduced (see the news article from Reuters (2024)). Pushing for decisions that are hard to reverse and threaten or annoy powerful actors in the system is likely to create resistance, preventing the desired results (Seelos & Mair, 2018). Moreover, addressing the conflict between agriculture and biodiversity through regional-level collaboration and local land-use strategies seems vital (Lécuyer et al., 2021).

As Seelos and Mair (2018, p. 40) concluded based on the successful transformation case studies: "*Do things right before doing the right things*". Perhaps successful transformation pathways are achieved by aiming at smaller successes, actively learning from the experiences, gaining the trust and partnership of farmers and their representatives, and creating a good reputation as an organisation. Advocating for ambitious environmental regulations may seem like a quick way to address biodiversity loss. However, their success seems unlikely without using sufficient time and resources in transparent and inclusive negotiation and consensus-building processes. Consequently, if the goal is to implement ambitious environmental interventions, the importance of allocating enough time and utilising skilled facilitators for consensus building should not be underestimated (Chapin et al., 2012).

4.6 Reflections on the methods

In this chapter, I delve into the challenges and opportunities encountered in employing CLDs in a participatory manner within the context of agri-environmental research. I explore the methodological decisions made during the research process, their implications for stakeholder engagement, and the balance between scientific knowledge and practical insights. This chapter answers the last research question, "*What are the challenges and opportunities of using Causal Loop Diagrams in a participatory manner in agri-environmental research?"*

The purposeful selection of participants resulted in relatively diverse expertise with sufficient similarities in the perspectives that made their integration into the mind maps and meaningful discussion possible. Around ten participants were highlighted by Sedlacko et al. (2014) for balancing the representation of diverse perspectives without too many conflicting ones. The long discussion regarding the goal of biodiversity promotion in the participatory system mapping workshop indicates that while diverse perspectives were present, the available time would not have been sufficient to include more conflicting perspectives. Chapin et al. (2012) highlighted in their case studies that successful negotiation to reach a consensus on long-term sustainability goals was possible for two reasons. Either the participants had relatively homogenous goals or reached a consensus after a time-consuming negotiation process. As long-term negotiation regarding the goals was not possible in the frame of my thesis work, the selection of participants with relatively homogeneous goals was a better solution. However, as reflected in the results, some areas of the system were underrepresented, notably market and value chain-related issues. The knowledge gaps in the CLD indicate that stakeholders concerned about biodiversity promotion might not sufficiently consider value chains and landscape complexity aspects. The research approach combined scientific knowledge and stakeholder insights. The latter was given more value to avoid overvaluation of scientific knowledge, as criticised by Anderson and Leach (2019).

Furthermore, the farmers represented here are not representative of the general population. The farmers showed high motivation to promote biodiversity and are part of multifunctional value chains, such as organic or ÖLN. Therefore, the findings are taking a stronger perspective on how to enable farmers who already have some level of motivation to promote biodiversity. The aspects of how to motivate a farmer who has contrasting worldviews, perspectives and attitudes to biodiversity promotion are not addressed at the same level. Thus, the ToC presented here should also be considered as targeted for enabling farmers who have positive attitudes towards biodiversity promotion to achieve better results. The examples of system transformation presented by Seelos and Mair (2018), show how creating successful small-scale examples can be more effective in the long term than trying to reach the goal quickly by forcefully trying to reach outcomes in which the stakeholders are not interested. Thus, I argue that focusing on farmers motivated to promote biodiversity is more likely to be successful than targeting the whole farming population.

Close stakeholder engagement and participatory system mapping have many benefits, as discussed in Chapter 2. However, my challenges included creating meaningful stakeholder engagement with limited resources, time, and language barriers. My choice to build the CLD by integrating mind maps from the interviews instead of building it in a group setting reduced the time individual stakeholders needed to provide. Creating system maps in a group setting typically takes a series of workshops where the stakeholders are required to participate (Barbrook-Johnson & Penn, 2022b), and the result typically contains inconsistencies, duplicities and underdeveloped system structures (Sedlacko et al., 2014). I also had to exclude some relationships added in the workshop, as they were illogical when the whole CLD was considered. Furthermore, participants' fatigue is a real risk which needs to be considered in stakeholder engagement (Sedlacko et al., 2014). On the other hand, engaging the stakeholders individually allowed them to express their opinions without being influenced by others (Deviney et al., 2023). This was relevant in the ZiBiF project as it allowed the participants to freely express critiques of the project without the presence of other project members. The benefits of creating shared understanding and collaborative learning (Anderson & Leach, 2019; Davila et al., 2020) were experienced through the validation process and in the participatory system mapping workshop. However, more sessions would have been necessary for the participants to comprehensively understand and discuss the CLD.

While the participants had varying engagement with visualising the mind maps during the interviews, it helped facilitate system thinking. The visualisation helped to deepen the discussion, to make underlying assumptions visible and to identify knowledge gaps (Dentoni et al., 2022; Sedlacko et al., 2014). Furthermore, I recommend visualisation during the interview process, as it helped me to make my interpretations transparent to the participants. Therefore, I received feedback and validated the mind map during the interview. It also prepared the participants for the validation process and participatory system mapping workshop.

Inherent subjectivism is a quality of CLD that should be considered carefully. The subjective nature is necessary to discover how the actors understand the system and envision change (Van Den Broek et al., 2024). Thus, the CLD and ToC represent my interpretations of the diverse perspectives represented by the participants (Wilkinson et al., 2021). Ultimately, the researcher or facilitator has the power to decide what is included and how it is visualised in the CLD (Barbrook-Johnson & Penn, 2022b). For example, in both groups, the participants discussed whether the factors of “habitat management efficiency” should be changed to effectivity (seven participants). These participants gave less value to lost opportunity cost, while two participants who preferred the term efficiency highlighted its importance. My decision was to keep the term efficiency, as important aspects related to the trade-offs farmers face would have been otherwise lost (see Box 1 in Appendix B: Research memos).

Mapping the factors and relationships without focusing on feedback loops caused a lack of information regarding the feedback mechanism which emerged from the system. While the participants had described some feedback mechanisms, for many of the feedback loops, I did not have detailed explanations of why and how they would function in the way they were visualised. However, the validation processes I employed helped to minimise misinterpretations and gaps in the CLD. An alternative method published after my data collection would be to focus on synthesising feedback stories. In this process, the participants are focused on the feedback loops (Rajah & Kopainsky, 2024). While the research participants engaged with the feedback loops during the validation, the interpretation of the feedback loops relied on me. Furthermore, the same system structures can be visualised (Crielaard et al., 2023) and named in multiple ways (effectivity versus efficiency). In the workshop, some participants understood and agreed with the visualisation more than others. Keeping a research memo regarding the CLD's development helped me reflect on potential bias caused by my assumptions and interpretations. Furthermore, feedback and criticism from peers and validation processes with the participants were vital for minimising researcher bias.

I combined the translation process with requiring criticism and feedback on the CLD from my peers. The language barrier complexified the process, and some meanings and cultural nuances might have been lost in translation. However, the constant switching between languages and reflective discussions during translation forced me to consider and clarify the meanings and relationships of the factors and consider their meaning from different perspectives. Therefore, I find that using multiple languages during the research process can have benefits, presuming that reliable translation is possible.

The validation of single statements adapted from a method used by Deviney et al. (2023) caused some issues. Taking the statements out of the context of the system undermined system thinking. As outlined in the chapter 4.2.7, factors are interdependent and need to be considered together. However, the participants perceived analysing the complete CLD as overwhelming. Therefore, the statements were combined with pictures of individual feedback loops of which the relationships are part of. Also, conclusions of supporting statements from the interviews were presented with the causal loops. The validation process proved to be both necessary and fruitful. Statements and relationships perceived as too simplistic were challenged, and the feedback provided deeper insights into the system. The CLD was modified and validated again at the beginning of the workshop. However, in the workshop, the participants were shown the complete CLD (not the individual loops), and the time was not sufficient for them to analyse the whole system. The complexity of the CLD might have been difficult to understand, especially for participants who had not participated in the interviews. In addition, rather than validating the system dynamics, the discussion largely revolved around details such as whether the factor name or the polarity of an individual relationship is correct. Facilitating the discussion away from details and towards considering the system dynamics at large might also help. Moreover, allowing more time to discuss the CLD in detail seems necessary, especially if new participants are involved in the analysis.

As pointed out by Meadows (2008, Chapter 6), actors of the system intuitively know where to find leverage points but often push them in the wrong direction. Identifying the actual direction in which leverage points should be pushed is often counterintuitive and takes long learning processes. Identifying leverage points based on network analysis is also misleading, as the current evaluation methods are not equipped to deal with the complexity of CLDs (Crielaard et al., 2023). Combining both network analysis and stakeholder insights helped me to minimise aspects left unnoticed. Nevertheless, the CLD and ToC are neither complete nor perfect. The development of CLDs and ToC should be a continuous learning process. My observation is that the CLD facilitated actors to engage in profound discussions regarding the underlying assumptions behind the causal connections.

While the complete CLD was perceived as too complex for a quick presentation, the ToC created a more simplified summary of the results. I found combining the CLD and ToC a promising approach for accounting for complexity. However, the ToC lacks the level of detail required to implement interventions. Nevertheless, the participants who provided feedback (four ZiBiF project team members in a Zoom meeting and one farmer via email) found the synthesis of the findings relevant and valid.

Lastly, I reflect on how the typical limitations of food and agricultural systems thinking research outlined by Dentoni et al. (2022) were addressed. The first limitation is the extensive focus on agri-food value chains due to setting boundaries that keep the participants away from broader socio-ecological interactions. While the focus of the participants was directed towards habitat and ecological quality on agricultural land, the interview themes organised around the Multi-Level Perspective framework encouraged consideration of wider aspects. The identified factors illustrate that a broad set of aspects were considered, from the practical implementation of biodiversity promotion to the political debates. Controversially, the agri-food value chains were underrepresented in the CLD. The second limitation is persistent linearity, where actions are assumed to lead to consequences without considering how the system itself influences those actions. Examples, such as obligatory protection of farmland and financial compensation for biodiversity promotion, exemplify how the indirect effects of potential interventions were considered. The combination of different interventions and leverage points to overcome barriers and lock-ins was highlighted. The third limitation is the assumption that change can be planned. The need for continuous learning and adaptation to account for the emergent processes of the system is acknowledged in the findings.

4.7 Study limitations

The CLD and ToC reflect my interpretations of the perspectives and assumptions of the research participants. Although I engaged in reflection, validation, and peer criticism to minimise the impact of my own assumptions, the resulting system representation is inherently subjective. It captures the issues of biodiversity promotion on agricultural land as perceived by the participants but does not provide a complete or universally objective representation of the system. In addition, the feedback loops in the CLD were identified manually due to the unavailability of automated tools or software for identifying such loops in CLDs. This manual process introduces the possibility of missing or misrepresenting feedback dynamics.

The absence of a comprehensive representation of perspectives, such as value chain actors, further limits the comprehensiveness of the findings. The study primarily involved farmers motivated to promote biodiversity, many of whom are part of multifunctional value chains (e.g., organic or ÖLN). This limits the applicability of the findings to farmers with differing perspectives, such as those more focused on maximising production or with less interest in biodiversity. Furthermore, certain aspects of the system, such as market dynamics, value chain structures, and dietary changes, were underrepresented in this study. These elements are crucial for understanding the systemic barriers and opportunities for biodiversity promotion, and their exclusion from the CLD limits the scope of the findings.

The participatory system mapping workshop was limited in duration, constraining the depth of discussion and the participants' ability to fully grasp the system dynamics and leverage points. While the workshop facilitated meaningful engagement and system thinking, the complexity of the CLD made it difficult for participants to reach a consensus or fully explore the system's feedback mechanisms. Increasing the number of workshops would allow for deeper engagement, improved understanding of system dynamics, and greater refinement of the CLD. However, cost, time, and logistical challenges often make extended participatory processes unfeasible, especially within the constraints of a master's thesis or similar projects. To address resource limitations, I constructed the mental models through interviews and validated the CLD using an online survey. While this approach ensured stakeholder input and minimised costs, it reduced opportunities for collaborative learning, which could have enriched the CLD.

This study highlights the potential of participatory CLDs and ToCs for fostering systems thinking and identifying leverage points. The limitations of representation, time, and resources must be acknowledged. While navigating these challenges, the findings of this study underscore the value of participatory methods for engaging stakeholders, uncovering systemic dynamics, and co-creating pathways toward biodiversity-friendly agriculture even when time and resources are limited.

5 Conclusions and recommendations

Acknowledging the need for agri-food system transformation, the "deep leverage points" approach of Meadows (1999) has been suggested as an approach to identify areas in complex systems with the potential to create fundamental changes (Abson et al., 2016; Davelaar, 2021; Dorninger et al., 2020). Classifying leverage points requires an understanding of the alignment of leverage with system behaviour, as illustrated in Figure 1 on page 11 (Davelaar, 2021). Agri-food systems are characterised by lock-in mechanisms preventing sustainability transformation. While some of them are generalisable in multiple agri-food systems, context-tailored solutions are often necessary (Conti et al., 2021; T. G.

Williams et al., 2024). Considering this, causal loop diagrams (CLDs) created with stakeholder insights generate an understanding of the issues grounded in the realities of societal actors (Dentoni et al., 2022). Therefore, I have selected system lenses combined with participatory approaches to find out how to enable transformative processes towards a biodiversity-friendly agricultural system in Switzerland. In Switzerland, improving habitat and ecological quality is central to biodiversity promotion schemes. As a foundation for answering my research questions, I developed a CLD based on stakeholders' insights. The CLD only illustrates the structures of the agricultural system that were deemed most important for biodiversity promotion. I will start by answering the first research question: "*What are the barriers and leverage points for improving habitat and ecological quality on agricultural land in Switzerland?*"

I identified lock-ins and barriers to biodiversity promotion on agricultural land in Switzerland from the CLD. The primary lock-in is created around farmers balancing trade-offs between biodiversity promotion and the economic sustainability of their farms. With the current capacity of farmers and market incentives, biodiversity promotion is not economically viable. While biodiversity promotion schemes offer financial compensation for farmers, it is often not enough to cover the opportunity cost due to the high efforts and restrictions related to them. For example, the more common action-based schemes of the Swiss direct payment system restrict farmers' management flexibility. Therefore, farmer's ability to engage in efficient biodiversity promotion is reduced. As an outcome, the farmer's motivation to promote biodiversity remains low, and the desired habitat and ecological quality are not reached. Moreover, the opinions at the societal level are polarised. The actors of agri-food value chains tend to defend the status quo, arguing for food security and focusing on maximising production (T. G. Williams et al., 2024). Meanwhile, strict environmental regulations such as the obligatory protection of farmland force farmers into dire straits. Moreover, society blaming farmers for environmental problems while individuals are not willing to pay a higher price for sustainable products drives farmers to take a defensive stand. The trade-offs between biodiversity promotion and agricultural production and the polarisation of opinions were identified as major barriers to collaborative solutions necessary for efficient biodiversity promotion. In summary, the identified barriers are:

- Farmers lack management flexibility due to high regulations
- High administrative burden for the farmers
- Obligatory protection of farmland (Naturschutzflächen)
- Low willingness of consumers to pay for biodiversity labels
- Dominance of agro-industrial value chains
- Trade-offs between biodiversity promotion and agricultural production

- Polarisation of opinions

Farmers lack the necessary capacity and knowledge to engage in effective biodiversity promotion. System analysis indicated that farmers' capacity and knowledge of biodiversity act as bottlenecks in the system. Farmer's free capacity, referring to the resources, time, and freedoms farmers do not use or lose when performing their core business activities, is the most influential factor in the CLD. For example, the impact of increasing farmers' knowledge will remain indifferent if the farmers cannot apply it due to strict regulations.

The participants identified increasing financial compensation and farm-tailored advice and training as actionable points to increase farmers' capacity and knowledge. Financial compensation can be identified as influential from the CLD. It activates all the reinforcing feedback loops of the CLD, triggering change processes in the system. Proper compensation improves farmer’s motivation to promote biodiversity. However, most financial compensation is related to bureaucracy, which reduces farmers' free capacity due to administrative burdens and management restrictions. Hence, administrative efforts and restrictive regulations need to be minimised for financial compensation to be effective.

Furthermore, there is a need to increase the feeling of farmers that their efforts are appreciated. In the current situation, society communicates mistrust and unappreciation to farmers through strict environmental regulations. Therefore, while the farmers may fulfil the minimum regulations, their motivation to engage in effective biodiversity promotion is low. Providing higher compensation for biodiversity promotion, farm-tailored advice, and acknowledgement of farmers' local ecological knowledge were assumed to increase farmers’ feelings of appreciation. In summary, the identified leverage points were:

- Increasing farmer's free capacity (finances, time and freedoms)
- Increasing and acknowledging Farmer's biodiversity and local ecological knowledge
- Higher financial compensation for biodiversity promotion
- Provisioning of farm-tailored advice and training
- Increasing farmers’ feelings of appreciation

The CLD with leverage points and barriers can be found on page 70, Figure 14.

The workshop participants did not recognise some potentially influential factors as leverage points. Notably, site-specific management, especially if applied collaboratively at the landscape level, has multiple desirable impacts. Site-specific management refers to adapting the goals and management to the area’s potential in relation to the regional and national goals. This could increase the efficiency of habitat management and input use (e.g. pesticides, fertilisers and labour). Hence, the trade-offs between biodiversity promotion and agricultural production are reduced. Therefore, site-specific management reduces the opportunity cost of biodiversity promotion, increases farm profitability, and reduces agricultural pollution caused by the overuse of inputs. However, the current lack of farmers' capacity, knowledge, and collaboration prevents effective site-specific management. That being said, ecosystem services provided by biodiversity are a necessity for food security. However, we lack a deeper understanding of the interplay between agriculture and biodiversity. Nevertheless, scientific evidence demonstrates that the trade-offs between biodiversity promotion and agricultural production can be minimised with site-specific goal setting and management applied at the landscape level (Ekroos et al., 2014; Kleijn et al., 2019; Tscharntke et al., 2021). However, this would require dialogue and collaboration between interest groups, which is currently hindered due to the high polarisation of opinions.

Subsequently, the workshop participants highlighted the need for higher farmer inclusion and dialogue to clarify biodiversity promotion goals. Similarly, scientific literature confirms the need for more collaborative solutions (Fleury et al., 2015; Klebl et al., 2024; Lécuyer et al., 2021; Maas et al., 2021). With the collaboration and empowerment of farmers being central, interventions to increase farmers' free capacity and knowledge were identified. That brings me to answer the second research question, “*Which transformation pathways do the stakeholders envision for a biodiversity-friendly agricultural system in Switzerland?”* The visualisation of the pathways can be seen in the Theory of Change (ToC) diagram in Figure 15 on page 76.

The general need for increasing financial compensation for biodiversity promotion was recognised. Furthermore, a compensation system with minimal bureaucracy and restrictions was suggested. Such a compensation system was envisioned to allow farmers to experiment and innovate for efficient biodiversity promotion. Thus, the farmers could apply their knowledge. After ensuring that the farmers can apply their knowledge, the need for more biodiversity knowledge was recognised. While biodiversity-related knowledge is already available, the need to strengthen the provisioning of knowledge to farmers was suggested. Envisioned interventions included increasing biodiversity topics in basic agricultural education while providing practical training programs and farm-tailored advice. The farm-tailored advice was envisioned to take a whole farm approach, considering both biodiversity and economic goals. The importance of knowledge for biodiversity promotion is widely acknowledged in the scientific community (Dorninger et al., 2020; Klebl et al., 2024). However, my findings highlight that knowledge is not a panacea for fixing all issues but a leverage point that must be applied strategically in combination with structural changes.

I identified two more interventions from the interviews. The first one is the landscape approach for biodiversity promotion, which is discussed in connection with site-specific management. While compensating farmers for higher habitat quality or connectivity of habitats already exists in Switzerland, the need for more landscape-scale collaboration was recognised in the interviews and confirmed by scientific literature (Lécuyer et al., 2021; Tscharntke et al., 2005). The second intervention is also related to higher payments for higher quality. Such systems, with result-based payments, were highlighted in the interviews to increase farmers' motivation to promote biodiversity and to increase peer support for biodiversity promotion among farmers. While limitations still exist for such payments (Canessa et al., 2024), the benefits of result-based payments have been confirmed in the scientific literature (Canessa et al., 2024; Herzon et al., 2018; Mack et al., 2020). In summary, the identified interventions are:

- Higher financial compensation for biodiversity promotion
- Economic support for experimentation
- Integrating biodiversity topics in the basic education of farmers
- Higher availability of practical training programs in biodiversity promotion/ecology
- Provisioning of farm-tailored advice and training with a goal
- Applying the landscape approach for biodiversity promotion
- More quality-based payments (such as “goal-oriented biodiversity promotion”)

Together, these interventions create a potential pathway towards sustainable system transformation where shallow and deep leverage points are triggered. Changing the compensation structures through economic support for experimentation, quality-based payments, and landscape approach allows farmers to apply knowledge and thus motivate them to acquire it. The desirable change is further amplified by strengthening the institutional capacities for knowledge provisioning.

However, in the current political context, ambitious environmental interventions are blocked due to polarised opinions. Consequently, my recommendation is to build experience, trust, and collaboration through smaller-scale success stories until sufficient support is gained for the initiative/project. Furthermore, the continued inclusion of farmers and consensus building seems vital due to the trade-offs between agricultural production and biodiversity promotion. On the other hand, advocating for stricter environmental regulations for the farmers might backfire. While the direct impact of the regulations may be positive on habitat and ecological quality, increasing them would also strengthen the barriers, reducing biodiversity promotion efficiency. Furthermore, the polarisation of opinions would likely increase due to the negative consequences to farmers and reduced feeling of appreciation. Therefore, any further initiatives for biodiversity promotion might be blocked by farmers and their representatives, as was seen with the last biodiversity initiative in September 2024 (Reuters, 2024).

These findings are based on the insights of stakeholders identified as key experts in biodiversity promotion on agricultural land in Switzerland. Considering the ambiguity of system-based approaches in agricultural research (Dentoni et al., 2022), I will reflect on the last research question, "*What are the challenges and opportunities of using Causal Loop Diagrams in a participatory manner in agri-environmental research?"*

System mapping and analysis offer an opportunity to integrate the diverse knowledge of multiple stakeholders. The visualisation process increases collaborative learning as the underlying assumptions of participants' mental models are discussed. Subsequently, the challenge is to integrate diverse perspectives into one CLD. Collaborative learning with stakeholders with conflicting worldviews is possible. However, achieving consensus takes long group mapping sessions. Often, time and resources are limited (Barbrook-Johnson & Penn, 2022b; Chapin et al., 2012); thus, investing the necessary time in consensus-building is not always possible.

I balanced the need for diverse knowledge and substantial consensus with a careful participant selection process. With the opportunity to collaborate with the ZiBiF goal-oriented biodiversity promotion project in Switzerland, I could reach stakeholders with diverse expertise in biodiversity promotion on agricultural land. While the project participants had diverse perspectives and expertise, they shared a consensus that the Swiss system needs reform to promote biodiversity-friendly agriculture. However, participants' priorities regarding the type of biodiversity that should be promoted varied (e.g. functional versus species biodiversity). I identified ten interview participants from the ZiBiF project as key experts in biodiversity promotion from practical, scientific, educational, and policy perspectives. Furthermore, through the workshop, perspectives outside of the ZiBiF project were added to the research. For example, civil society and environmental advocates were represented through the workshop participants. Admittedly, due to the selection bias towards actors motivated to promote biodiversity, the research takes a strong perspective on enabling actors to promote biodiversity. It does not consider how to motivate or force system actors who are firmly against biodiversity promotion. Furthermore, the ZiBiF project lacked representatives from value chains (apart from the farmers). The results reflected this through the factors focused on the CLD. I identified a lack of stakeholder insights related to markets, value chains and dietary patterns. Combining stakeholder insights with scientific literature helped me to identify these knowledge gaps. Furthermore, the leverage points and interventions do not include market-based incentives for biodiversity promotion.

The second challenge was meaningfully engaging with the participants with the limited theses writing time (six months) without causing participant fatigue. My solution was to build the CLD in iterative steps, combining interviews, a validation survey and a participatory system mapping workshop. While the approach limited the potential for collaborative learning, it allowed individual participants to express themselves more freely. Furthermore, visualising the mental maps of the participants during the interview and the validation survey reduced researcher bias in the interpretation. My experience with combining the different approaches for building the CLD was positive.

However, there are four aspects that I would consider developing further, indicating potential future research areas. Firstly, I would include value-chain actors from alternative food networks to better understand the market opportunities. Secondly, I would adopt a higher focus on feedback mechanisms in the interview process, for example, from Rajah and Kopainsky (2024). The visualisation alone facilitated system thinking, and I was able to identify many feedback mechanisms. However, often, the feedback loops were only explained in one direction. Therefore, some ambiguity was left about whether the feedback could function in both directions and, if yes, the narrative behind it was unknown to me. Thirdly, the validation of single sentences seemed to hinder system thinking. While I provided pictures of the feedback loops with the sentences, some participants focused on individual relationships without considering the interdependencies between the factors. Therefore, I would recommend developing processes where interconnected factors are validated together. Lastly, the identification of leverage points could have been improved with an additional participatory system mapping session or more efficient methods to discover the system dynamics in a group setting. Many participants perceived that one session (total workshop time of two hours) was too short to engage in a deeper analysis of the CLD. Nevertheless, my subsequent system analysis (centrality values and analysis of the feedback loops) confirms that the identified leverage points are important factors in the system. Therefore, I conclude that while the workshop felt overwhelming for the participants, they did engage in system thinking. Nevertheless, I would recommend the development of network and feedback loop analysis accounting for the complexity of CLDs, which can be used in a participatory setting. I believe such tools would make participatory system mapping more engaging and facilitate effective system thinking in a group setting. Moreover, for further research, I would recommend utilising the "value network map" of actors combined with the CLD, as Dentoni et al. (2022) recommend. Utilising the value network map would help the participants position themselves in the system to discover what they can do to solve the identified issues, suggest who could help them to address the issues, and reconfigure the network of actors to facilitate solving the issues.

In summary, identifying leverage points with participatory CLDs demonstrates an actionable approach to identifying potential pathways towards sustainability transformations. The research underscores the potential of participatory system mapping to align diverse stakeholder perspectives and co-create actionable solutions. The use of CLDs in this context proved valuable for visualising feedback loops, facilitating dialogue, and identifying leverage points. However, challenges such as data subjectivity and the time-intensive nature of participatory processes must be acknowledged. The findings reveal critical barriers to biodiversity promotion, including limited financial incentives, rigid regulatory frameworks, and lock-ins prioritising agricultural production over ecological sustainability. Key leverage points identified include enhancing farmers' management flexibility, economic capacity, and biodiversity knowledge, as well as increasing social appreciation for farmers' roles as stewards of land. Notably, debates about prioritising biodiversity versus agricultural productivity highlight the need for integrated strategies at the national and landscape levels that balance these competing objectives. Subsequently, my findings show that farmers should be allowed more freedom rather than increasing mandatory environmental regulations. Effective governmental compensation systems for biodiversity promotion and strengthened institutional capacity for knowledge provisioning should be combined with market incentives. Furthermore, collaborative consensus-building processes, including diverse interest groups and farmers, should be utilised in the design of biodiversity promotion schemes. Combining these strategies may enable system transformation towards biodiversity-friendly agricultural systems in Switzerland.

6 References

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7 Appendices

7.1 Appendix A: Interview questions

Guiding questions and themes

Established Practices and Structures (Regime level in the MLP)

- Can you describe the prevailing agricultural practices and trends in the Canton of Zurich which influence habitat quality?
- What are the dominant policies, regulations, or norms that shape agricultural practices and land management decisions?
- Which other factors of the agricultural system or local economy are likely to be influenced by changes in habitat quality?

External Pressures and Contextual Factors (Landscape level in the MLP)

- Which broader environmental policies or regulations influence efforts to enhance habitat quality?
- Are economic or market pressures affecting agricultural practices and land use decisions?
- Are there public opinions or societal values regarding biodiversity conservation that impact agricultural practices in your community?

Innovation – Goal-Oriented Biodiversity Promotion (Nice level in the MLP)

- Which specific practices or strategies does the project promote to enhance the habitat quality of agricultural land?
- What are the main barriers or challenges encountered in implementing and sustaining the "goal-oriented biodiversity promotion" project?
- Which barrier do you predict the project to face in the future?
- What factors have facilitated the success and continuity of the project?

Farm/User level

- Which factors at the farm level influence habitat quality?
- Which factors at the farm level are influenced by habitat quality?

7.2 Appendix B: Research memos

Appendix A contains parts of my research memo, explaining in more detail my interpretations and decisions made when constructing the Causal Loop Diagram from the stakeholder insights.

Box 1: Development of the relationships between habitat management effort, efficiency and habitat and ecological quality

Here, I explain how the relationship between "habitat management effort" and "habitat management efficiency" developed through the stakeholder's engagement.

The complex relationship between habitat management effort, efficiency, and habitat and ecological quality evolved during the CLD development process to illustrate how biodiversity promotion can conflict or have synergies with agricultural production. The factor "habitat management effort" was added after the workshop. During the workshop, the relationship between "habitat management efficiency" and "agricultural production" was changed from a negative to a positive connection. Based on the interviews, I had interpreted the connection as a negative relationship as in the interviews, biodiversity-friendly measures were mostly seen to reduce agricultural production: *"You get not much nutrition for the plants, and so you get the higher biodiversity, but this is actually in contrast to high productivity."* (Stakeholder nr. 2)

However, during the workshop, both groups wanted to change the relationship to a positive one, arguing that biodiversity promotion and agricultural production do not have to be contradictory. Some workshop participants were also confused about the meaning of "habitat management efficiency", indicating that the terms and their relationships are not easily understood. I added the factor "habitat management effort" in the CLD with a connection to "habitat management efficiency" with negative polarity to conserve the narrative highlighted in the interviews that, often, farmers have to compromise between biodiversity promotion and agricultural production. Figure 7 shows the factors and the narrative of trade-offs between biodiversity promotion and agricultural production, illustrated in the CLD.

Box 2: Farmer's knowledge and management flexibility

Here, I explain in more detail why the acknowledgement of farmers' knowledge and management flexibility is vital for strengthening the reinforcing feedback loops.

The lack of farmers being able to apply their knowledge was a highly discussed point. The issue that in the current biodiversity promotion system, due to a lack of management flexibility, farmers are not able to apply their knowledge:

> *"The weak point is that this is due to the fact that our direct payment system actually doesn't allow at all, to put it a bit exaggeratedly, for the farmer to then apply this knowledge." (Stakeholder nr. 1, workshop)*

One biodiversity advisor said that in her experience, the farmers are only interested in biodiversity knowledge if they are incentivised to apply it, which is the case in ZiBiF but not in most common biodiversity schemes:

> *"The ones who don't have rules anymore really did want to reach something, and because the ZiBiF has different quality levels, and the higher you get, the more money you get, then the farmers also have higher motivation." (Advisor nr. 3)*

Therefore, the strength of the connections between “farmer’s biodiversity and local ecological knowledge” and “habitat management efficiency” as well as “motivation to promote biodiversity” and “farmer’s biodiversity and local ecological knowledge” depends on how much freedom the farmers have.

Box 3: Profitability

Here, I explain in more detail the development of the factors influencing farm profitability. First, I will explain how farmers generate profits from agricultural production. In the end, I will explain the relationship between “financial compensation for biodiversity promotion” and “profitability”.

Profitability is typically understood as Profit=Revenue−Expenses: “*Costs and revenue. That's actually the definition of production level and profitability.”* (Advisor nr. 1, workshop).

The expenses include the efforts the farmer sees to obtain the revenue:

> *“For me, profitability means that the effort corresponds to the yield or is lower. A high level of farming intensity must also generate a high yield; otherwise, the math will not add up. A low level of intensity also generates little product.” (Advisor nr. 1, validation survey)*

The expenses are included in the "intensity of input use", with inputs referring to everything the farmer is investing in the process of obtaining the yield. Generally, inputs refer to pesticides, fertilisers, labour, and fuel used in the operations. The "efficiency" in the input use refers to finding the balance where inputs are optimised for the location and market price of the crop.

> *"That means that there is an optimum level of production where you need resources, and of course, the location is also important. A good location with enough fertiliser, but not too much fertiliser; if you give too much, it's not good either." (Advisor nr. 1, workshop)*

The revenue is generated through sales of agricultural products; thus, "agricultural production" increases profitability. However, the market factors influence the sales:

> *"The level of production is then in kilos, and that doesn't have to match." (Advisor nr. 1, workshop)*

> *"Then it has to be in francs; then it's right again." (Farmer nr. 5)*

As stated in the workshop, the measurement of "agricultural production" has to be based on the market value. In summary, “agricultural production” measured based on the market value represents revenue, thus increasing “profitability”. “Efficiency of input use” represents the cost. If the input use efficiency is reduced, then the cost increases. Therefore, “efficiency of input use” also increases “profitability.

Moreover, “financial compensation for biodiversity promotion” increases profitability. However, this is not always the case:

> *"Profitability only increases if the system is compensated in a target-oriented manner (as in ZiBiF). In the current DZV system, profitability does not really increase."(Advisor nr. 3, validation survey)*

In this case, the CDL rather illustrates the envisioned system structure for effective biodiversity promotion. In the workshop, the participants wanted to change the factor's name from financial incentives to financial compensation to highlight that it needs to be high enough to cover the farmers' biodiversity management efforts:

> *"I would also link financial incentives to profitability because it's like compensation, a substitute for the level of production, the level of income. Is it lower? That's clear, but then there is financial support. I don't agree with the word incentives; that's kind of like bait and switch, and that's not just that; that's something compensatory." (Advisor nr. 4, workshop)*

Hence, the relationship between "financial compensation for biodiversity promotion" and "profitability" is only valid if the compensation is high enough to cover the farmer's efforts.

Box 4: Agri-industrial value chains

Here, I discuss in detail the factor "agri-food value chains".

The research participants highlighted that the trajectory of agriculture in Switzerland is highly focused on food production:

> *"I think it's mainly intensive farming with food production or the concentration on food production. That has a strong influence on agriculture." (Farmer nr. 5)*

One participant acknowledged how high mechanisation due to the focus on food production has impacted the landscape complexity:

> *"Mechanisation in itself often has to do with the fact that plot sizes are increasing, of course. And that, of course, has a it's mainly the aesthetic impression that is changed. The larger fields often become monotonous, cleared landscapes or something, so the aesthetics are reduced from a social point of view. Conversely, of course, the quality in terms of yield |production quantity increases... And then, of course, depending on the biodiversity, the connectivity becomes more difficult because the larger the plots, the less connectivity is possible." (Stakeholder nr. 1)*

The same person discussed how the pressure from large retailers impacts farmers:

> *"In the sense that the specifications for these products are defined by these large-scale distributors. This then partly contradicts the expectations of society, for example, the use of pesticides. The wholesaler naturally demands the perfect products. But society expects no pesticides to be used. That is somehow contradictory. Ultimately, of course, this has an impact on the quality of the land, i.e. the quality of the habitat."(Stakeholder nr. 1, interview)*

While the agri-industrial value chain issues were discussed in detail by only one participant, multiple participants mentioned the negative impact of high focus on food production. Moreover, the lock-ins related to agri-industrial value chains significant according to scientific literature (Conti et al., 2021; T. G. Williams et al., 2024). Therefore, the factor was prioritised in the CLD, even if its impact is a bit unclear based on the interviews, and it has a limited number of meaningful connections.

Box 5: Recreational value of agricultural land

Here, I explain in the decision why the recreational value of agricultural land was not included in the Causal Loop Diagram.

While most considered habitat and ecological quality to increase recreational value, one farmer stated that in some areas, neat, poor-quality landscapes are perceived as more desirable:

> *"They don't do biodiversity, or yes, they do, but they are hidden. What can be seen is without conservation strips or networks. It's all for show, tourist-friendly farming." (Farmer nr. 2)*

Studies have also found that farmers' aesthetic preferences depend on what is perceived as good agricultural practices and are related to a farmer's reputation among peers. Typically, perceptions of good agricultural practices are connected to efficiency; therefore, regular large fields with monocultures and without weeds are preferred (Burton, 2012). Mapping such a complex relationship would have significantly increased the complexity of the CLD. Secondly, in the interviews, only a few connections were established between recreational value and other factors, reducing its importance during prioritisation.

Box 6: Additionality in the "goal-oriented biodiversity promotion" ZiBiF project

Here, I discuss the question of additionality in the ZiBiF project.

Canessa et al. (Canessa et al., 2023) highlight the need to consider additionality in the financial compensation systems for biodiversity. It refers to the economic efficiency perspective, where payments should produce positive behaviour that would not have occurred otherwise. In the interviews, two farmers indeed pointed out, that while ZiBiF increased their financial compensation, they did not need to change their management:

> *"We didn't change a lot since we were in ZiBiF because it's the way we did farm before. So we had the best quality grassland that wasn't in the 7[% extensively managed farmland as part of the proof of ecological performance part of the Swiss direct payment system] thing before. But it has high quality." (Farmer nr. 1)*

In this case, the farm was rather selected in the ZiBiF project as a successful example, whereas the farmer's motivation to join was also to prove that farmers can engage in successful biodiversity promotion when they are not part of strict regulatory systems:

> *"In the end, it was the motivation [to join ZiBiF] to show the government and all those biodiversity experts and all the people that it's possible to get more biodiversity by farming differently than they think now is the right way." (Farmer nr. 1)*

However, other farmers stated that while they understand the importance of biodiversity promotion, they would not be able to continue it successfully if it is not compensated sufficiently:

> *"When I do less, I think also, the quality gets back. And I'm a little bit afraid of that because the ZiBiF runs maybe like 3 or 4 years, and then it's finished. And then it depends on what Switzerland will do. And when they say we go to the old system, I think the quality goes back." (Farmer nr. 4)*

Thus, ZiBiF does have additionality. Furthermore, farmers successful in biodiversity promotion play an important role in the project for sharing practical knowledge, which on its own may also be worth compensating.

7.3 Appendix C: Tables

Appendix B contains the tables related to the interviews and system analysis.

Table 2: Interviews

Interest Group	Number of Participants	Duration	Form	Langue	Date	Validation
Project team: practitioner & government official	2	2 hours	Online	Eng	1.7.2024	Yes
Project team: practitioner	1	1 hour	Online	Eng	5.8.2024	Yes
Farmer: practitioner	1	1 hour	Online	Eng	5.8.2024	Yes
Project team: practitioner	1	1 hour	Online	Ger	14.8.2024	Yes
Farmer: practitioner	1	1 hour	Online	Eng	16.8.2024	No
Farmer: practitioner	1	1 hour	Online	Eng	22.8.2024	Yes
Project team: practitioner	1	1 hour	Online	De	26.8.2024	Yes
Farmer: practitioner	1	1 hour	On-site	De	6.9.2024	No
Farmer: practitioner	1	1 hour	Online	De	12.9.2024	Yes

Table 3: Factors and definitions

FACTOR	Definition
Administrative effort	Time and energy that farmers must spend on complying with regulations, managing paperwork, and meeting the requirements for receiving governmental subsidies and other programs.
Agricultural production	The amount of yield generated per unit area over a specified period, typically measured in terms of market value.

Agro-industrial value-chains	Networks within the agricultural and food production sector, characterised by power dynamics favouring large-scale, input-intensive farming and efficiency-driven practices.
Consumer demand for sustainability labels	Market demand and willingness to pay for certifications such as organic, Demeter or IP Suisse, which signify that agricultural products meet specific environmental and sustainability standards.
Efficiency of input use	The input intensity level (e.g. use of fertiliser, plant protection, energy in the form of mechanisation and time) where benefits are maximised, and drawbacks minimised for maximum farm profitability and long-term resilience.
Farmer's biodiversity & local ecological knowledge	The specific knowledge farmers need regarding the interactions between agricultural practices and natural ecosystems, e.g., ecological processes and site-specific environmental factors.
Farmer's free capacity	The resources, time, and flexibility available to farmers beyond core business activities.
Farmer's motivation to promote biodiversity	The internal and external factors that drive farmers to adopt practices aimed at enhancing biodiversity on their agricultural land.
Farm-tailored advice and training	Farmers receive tailored biodiversity advice from consultants during on-site meetings at their farms.
Feeling of appreciation	How farmers perceive their value in society, particularly in relation to their profession and role in managing land
Financial compensation for biodiversity promotion	Payments designed to encourage farmers to integrate biodiversity-promoting practices into their farming systems
Habitat and ecological quality	Habitat and ecological quality refer to the conditions in specific habitat types on agricultural land which support biodiversity and the health and integrity of ecosystems, with varying emphasis on specific needs of rare species or practical ecosystem functions.
Habitat management efficiency	The degree to which a farmer's actions effectively improve habitat and ecological quality relative to the effort invested, emphasising the optimal use of resources and the achievement of beneficial outcomes such as biodiversity enhancement and ecosystem services.
Habitat management effort	The total amount of actions and resources a farmer applies to improve habitat and ecological quality, regardless of the effectiveness or efficiency of these measures.
Landscape complexity	The diversity and arrangement of natural and agricultural elements in a landscape, encompassing composition (biodiverse non-crop areas), configuration (functional connectivity for species), and heterogeneity (spatial and temporal variability in land use and resources).
Management flexibility	The freedom and ability of farmers to adapt their practices to fit their personal goals without being strictly confined by regulations and rules.

Obligatory protection of farmland	Regulations that restrict farmers' management flexibility due to the high biodiversity value of their land, requiring it to be protected.
Polarisation of opinions	The growing divide between perspectives that prioritise maximising food production through intensive farming practices and those that advocate for promoting biodiversity.
Profitability	The financial success of a farming operation, typically measured by the difference between farm revenue and costs.
Site-specific management	A farming approach that tailors agricultural practices to the specific characteristics of the site, landscape and habitat.
Trade-offs between objectives	The perceived trade-offs between conflicting goals that farmers face, such as maximising food production while promoting biodiversity.

Table 4: Feedback loops

Factor	**Feedback loops the factor is part of**																	
Agricultural productivity	x	x	x	x	x		x	x	x									8
Efficiency of input use									x			x						2
Farmer's knowledge	x			x	x	x				x	x		x			x		8
Farmer's free capacity	x	x	x	x	x		x	x	x			x						9
Farmer's motivation	x	x	x	x	x	x	x			x	x		x	x	x	x		13
Feeling of appreciation	x	x				x											x	4
Habitat & ecological quality										x			x	x	x			4
Habitat management efficiency	x	x	x	x	x		x	x		x			x	x				10
Habitat management effort		x	x				x							x	x			5

Polarisation of opinions	x	x				x											x	4
Profitability	x	x	x	x	x		x	x	x			x						9
Site-specific management	x	x	x	x		x		x	x	x	x	x						10
Trade-offs between objectives	x	x	x	x		x					x							6
Number of factors	9	9	7	7	5	6	5	4	4	5	4	4	4	4	3	2	2	
Loop tag	R1	B1	B2	R2	R3	R4	B3	R5	R6	R7	R8	R9	R10	B4	R11	R12	R13	

Light red factors are the barriers, and green factors are the leverage points. Blue strips are the balancing feedback loops, and violet are the reinforcing feedback loops.

Table 5: System analysis metrics of the factors

Factor	**In-degree**	**Out-degree**	**Betweenness**	**Closeness**	**Eigenvector**	**Loops**
Administrative effort	2	1	4,6	0,3	0,0	0
Agricultural production	3	1	17,8	0,3	0,4	8
Agro-industrial value-chains	0	2	0,0	0,3	0,0	0
Consumer demand for sustainability labels	0	2	0,0	0,3	0,2	0
Efficiency of input use	1	3	17,9	0,4	0,5	2

Farmer's biodiversity & local ecological knowledge	2	3	57,4	0,4	0,2	8
Farmer's free capacity	3	2	51,3	0,3	1,0	9
Farmer's motivation to promote biodiversity	6	2	101,8	0,4	0,0	13
Farm-tailored advice and training	1	3	8,4	0,3	0,2	0
Feeling of appreciation	4	2	22,6	0,4	0,0	4
Financial compensation for biodiversity promotion	1	4	12,5	0,3	0,7	0
Habitat and ecological quality	5	1	34,7	0,3	0,7	4
Habitat management efficiency	3	2	30,6	0,3	0,5	10
Habitat management effort	1	2	21,8	0,2	0,0	5
Landscape complexity	1	1	6,0	0,2	0,0	0
Management flexibility	1	2	4,2	0,4	0,0	0

Obligatory protection of farmland	0	5	0,0	0,4	0,0	0
Polarisation of opinions	4	1	19,5	0,2	0,3	4
Profitability	3	1	33,8	0,3	0,3	9
Site-specific management	3	3	85,0	0,5	0,4	10
Trade-offs between objectives	1	2	27,0	0,3	0,2	6

Factors with blue frames were identified as leverage points by the research participants. Factors with orange frames were identified as barriers based on the interviews. The numbers are highlighted from highest (green) to lowest (red) for each measurement type. Higher in-degree indicates a factor as a potential indicator for systems volatility; high-outdegree potential high impact power. High betweenness centrality indicates a factor as a bottleneck for change, and high closeness centrality indicates a factor as a potential barrier. Eigenvector centrality tells which factors impact the influential factors, indicating their potential as leverage points (Murphy & Jones, 2020).

Table 6: Comparison of stakeholder insights and system analysis

Factor	System analysis	Stakeholder insights
Administrative effort	Low centrality metrics; not highlighted quantitatively.	Identified as a significant barrier, especially due to complex direct payment systems and rigid bureaucracy.
Agro-industrial value chains	Low quantitative significance with low centrality and feedback loop inclusion.	Identified as a significant systemic lock-in in the scientific literature, reducing landscape complexity and amplifying conflicts between production and biodiversity goals.
Efficiency of input use	High out-degree and eigenvector; a leverage point for direct systemic impact.	Not explicitly identified in stakeholder discussions but implied through challenges related to resource use and profitability.

Farm-tailored advice & training	All network values low, activates 4 balancing and eight reinforcing loops.	Identified as a potential intervention to increase farmers' knowledge.
Feeling of appreciation	Potential barrier and indicator for system volatility.	Identified as an important leverage point for increasing farmer's motivation.
Financial compensation	High out-degree indicting potential high impact as a leverage point but ignores negative effects of increased administration	Identified as an important leverage point for increasing farmer's motivation and reducing financial constrains.
Farmer's motivation	High in-degree and betweenness; low eigenvector indicates it is more influenced than influential.	Stakeholders perceive strict regulations and a lack of financial incentives as key barriers to motivation.
Farmer's knowledge	High betweenness and closeness; critical for enabling system change.	Identified as a leverage point. Farmers show interest in knowledge only when incentivised to apply it; rigid regulations reduce its utility.
Obligatory protection	Only high closeness; acts as a rigid systemic barrier.	Perceived as problematic due to reduced flexibility, increased "administrative effort", and demotivation, despite benefits for habitat quality.
Polarisation of opinions	High in-degree reflects systemic tensions, but low betweenness and closeness reduce its quantitative significance.	Recognised as a barrier due to societal conflicts between productivity and biodiversity, exacerbated by "agro-industrial value chains" and productivist attitudes.
Profitability	High closeness and feedback loop inclusion; a resilient barrier requiring systemic intervention.	Highlighted as a financial barrier.

Site-specific management	High betweenness and closeness; bridges biodiversity and production goals.	Recognised as a key area for addressing trade-offs but requires flexibility and farmer engagement to unlock potential.

8 Declaration of originality

I declare that this thesis is my own work and that, to the best of my knowledge, it contains no material previously published, or substantially overlapping with material submitted for the award of any other degree at any institution, except where due acknowledgment is made in the text.

Date and Signature of student